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INTEGRATED CONTROLLER EVALUATION

FINAL REPORT

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UNITED STATES ARMY AVIATION ENGINEERING FLIGHT ACTIVITY
EDWARDS AIR FORCE BASE, CALIFORNIA 93523

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The United States Army Aviation Engineering Flight Activity, in conjunction with the United States Army Human Engineering Laboratory (USAHEL), conducted a limited flight evaluation of an integrated control system installed in a JOH-58A helicopter. Flight tests were conducted at Aberdeen Proving Ground, Maryland, from 23 January through 19 February 1976. A total of 27 flights were conducted, consisting of 14 productive flight hours. Testing was performed to provide a

(continued)

20. Abstract

safety-of-flight envelope for future USAHEL tests, to determine the feasibility of the integrated controller concept, and to verify satisfactory operation of standard flight controls (right side) with the integrated flight control system installed. A safety-of-flight envelope was established for future USAHEL testing. The integrated controller concept could not be adequately evaluated because of the large number of shortcomings and deficiencies found with the initial design. Eight shortcomings and five deficiencies were noted during this evaluation. The most significant were the high control sensitivity in all controls and the poor control harmony between control axes. The standard control operated satisfactorily in conjunction with the integrated controller.

PREFACE

The United States Army Aviation Engineering Flight Activity wishes to acknowledge the cooperation and support provided during the integrated controller evaluation by the personnel of the Phillips Army Airfield Flight Detachment, Aberdeen Proving Ground (APG), Maryland; the Fire Prevention and Protection Division, APG; and the United States Army Human Engineering Laboratory, APG.

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INTRODUCTION

BACKGROUND

1. The United States Army Human Engineering Laboratory (USAHEL), Aberdeen Proving Ground (APG), Maryland, has been exploring the feasibility of integrating the conventional cyclic and collective controls of a helicopter into a single flight control. The principal advantage claimed for an integrated flight control is that it would enable the pilot to have one hand free during any flight mode which allows him to perform navigational tasks or operate subsystems or weapons. In addition, control grip complexity and training requirements may be reduced, and survivability could be increased. The USAHEL designed, fabricated, and tested an integrated controller on a GAT-II-H flight simulator. As a result of the feasibility tests, USAHEL modified a JOH-58A helicopter by installing a limited control authority integrated controller at the copilot station. The United States Army Aviation Systems Command (AVSCOM) requested (ref 1, app A) the United States Army Aviation Engineering Flight Activity (USAAEFA) to determine a safe flight envelope for the modified JOH-58A helicopter prior to a human factors evaluation of the integrated controller by USAHEL.

TEST OBJECTIVES

2. The objectives of this test program were as follows:

a. Conduct flight tests to provide safety-of-flight data for follow-on human factors flight tests of a JOH-58A equipped with an integrated controller.

b. Conduct a qualitative evaluation to determine the feasibility of the integrated controller concept.

c. Verify satisfactory operation of standard flight controls with the integrated flight control system installed.

DESCRIPTION

3. The integrated controller is designed to eliminate the need for separate collective and cyclic control devices. The integrated controller combines the collective and cyclic into a single flight control (photo A). It consists of a vertical column, hinged at the bottom, which when pulled toward the pilot increases collective pitch and when pushed forward decreases collective pitch. Attached to both sides of the collective column are hand grips which provide cyclic control and which may be operated independently. A hand grip, when pivoted around an axis extending through both hand grips, provides longitudinal pitch control. As the top of the grip rotates forward, nose-down control input is provided;

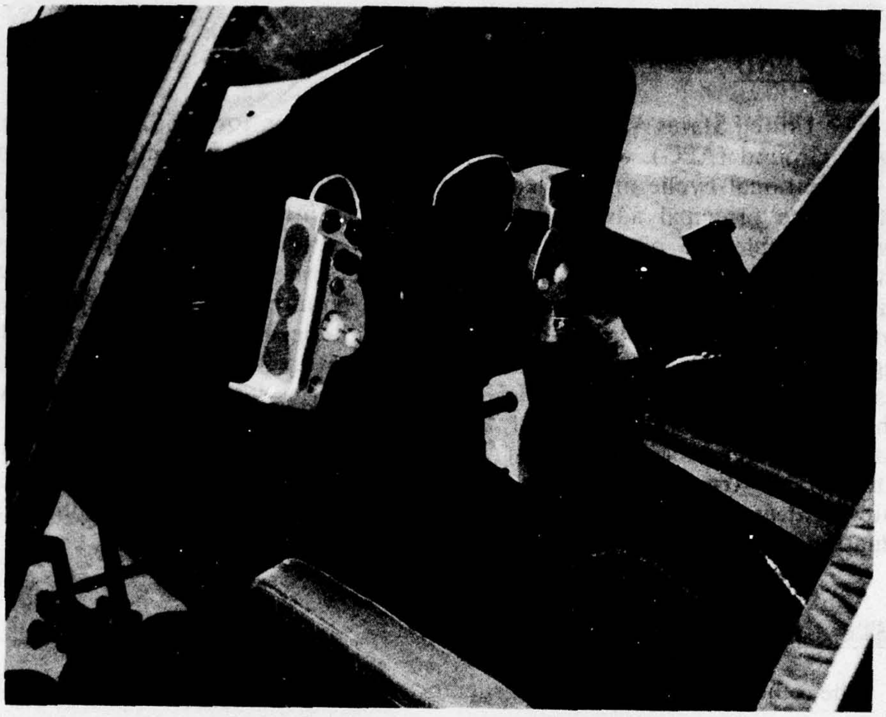


Photo A.

conversely, as the grips are rotated rearward, nose-up control input is provided. Clockwise rotation of either grip provides a right roll control input to the aircraft and a counterclockwise rotation of either grip provides a left roll control input. A more detailed description of the integrated controller may be found in appendix B.

TEST SCOPE

4. The integrated controller evaluation tests were conducted by USAAEFA at APG between 23 January and 19 February 1976. The tests required 14 productive hours of flight (27 flights). Maintenance support on the JOH-58A test aircraft was provided by Ross Aviation. Instrumentation support was provided by USAAEFA and USAHEL. The integrated controller was installed by USAHEL and Ross Aviation personnel. The limitations of the safety-of-flight releases (refs 2 through 6, app A) were observed throughout these tests.

5. Portions of the test results were compared to a previous OH-58A airworthiness and flight characteristics test (ref 7, app A). The test conditions are shown in table 1.

TEST METHODOLOGY

6. Standard engineering flight test methods used are outlined in the test plan (ref 8, app A) and are briefly described in the Results and Discussion section of this report. A Handling Qualities Rating Scale (HQRS) (app E) was used during the evaluation to assist in overall qualitative assessment of the integrated controller. Data analysis methods are described in appendix F.

7. Flight test data were hand-recorded by the safety pilot from test instruments in the pilot panel. Additional data were recorded by an 18-channel oscillograph. The instrumentation was installed by USAAEFA personnel and maintained by USAHEL personnel. A detailed list of the test instrumentation is presented in appendix C.

8. Integrated controller positions were determined relative to the conventional controls, as discussed in paragraph 9 and appendix B and are presented in figures 1 through 3, appendix G. The longitudinal integrated controller position of zero degree is the reference point for longitudinal control position. Zero degree was determined as the position when the hand grip was perpendicular with respect to the longitudinal plane of the aircraft. This zero position varied with changes in the collective controller vertical column position. Zero degree for the lateral integrated controller position was defined as the center of rotation.

Table 1. Test Conditions.[1]

Test	Average Density Altitude (ft)	Average Gross Weight (lb)	Average Center-of-Gravity Location (in.)	Calibrated Airspeed (kt)
Control system characteristics and control positions in trimmed forward flight	1300 to 2000	2600 to 2920	106.7 to 111.0	32 to 113
Static longitudinal stability	780 to 1560	2950	111.0	22 to 119
Static lateral-directional stability	2080	2600	106.6	89
Maneuvering stability	1020	2900	110.9	51 and 89
Controllability	-600 to 1400	2920	110.9	51 and 89
	-2500	2680	109.7	Zero
Low-speed flight	-2500	2660 to 2980	109.4 to 110.8	[2]Zero to 26
Mission maneuvers	-600 to 2500	2600 to 2980	106.6 to 111.0	Zero to 119
Simulated sudden engine failures	640 and 1280	2640 and 2940	106.7 and 111.0	30 to 110

[1]Rotor speed: 354 rpm.
[2]True airspeed.

RESULTS AND DISCUSSION

CONTROL SYSTEM CHARACTERISTICS

Static Test

Position Characteristics:

9. Position characteristics of the integrated controller were initially evaluated on the ground with the rotors and engine stopped. Hydraulic and electrical power were provided by an external source. Control positions in inches of longitudinal and lateral movement were calibrated on the conventional controls (right side). Measurements with a gunner's quadrant attached to the integrated controller provided controller movement in degrees relative to position of the conventional controls. Movements of the integrated controller versus movements of the standard controller are depicted in figures 1 through 3, appendix G. These measurements were made with the integrated controller collective pitch control in full aft, mid, and full forward positions.

10. The integrated controller has approximately 32 percent less longitudinal authority than the conventional control (fig. 1, app G). The amount of control authority reduction was not equal at both extremes of collective control travel. Approximately 1.1 inches of forward cyclic control were lost when the integrated controller was rotated full forward and 2.7 inches were lost with the controller rotated full aft. The decrease in control authority resulted from efforts to connect the integrated controller directly into the conventional controls and still provide the correct amount of control power and sensitivity. The effect of this reduced control authority on the evaluation is further discussed in paragraph 17. There was a 36-percent reduction in lateral control authority between the conventional control and the integrated controller. The conventional control had a full travel of 9.4 inches laterally. The total movement of the integrated controller laterally was 46 degrees and movement of the conventional control was 6.05 inches. Control sensitivity in roll was too high and is further discussed in paragraph 21.

11. As described in paragraph 1, appendix B, the control system was designed to give the safety pilot an override capability. When full control authority of the integrated controller had been reached, the safety pilot still had full control authority in any direction. Full control authority of the conventional controls was verified during ground tests. The standard flight controls installed on the right side operated satisfactorily with the integrated control system installed.

Control Force Characteristics:

12. Control force characteristics were evaluated under the conditions discussed in paragraph 9. Ground test data were later validated by in-flight evaluation. With the OH-58A augmented control system, a force gradient is induced in the control

system by an adjustable friction control (fig. A) and/or by the force trim system (magnetic brake and springs, photo 1, app D). In an unmodified OH-58A, use of adjustable friction results in a jerky pattern of control motion detrimental to smooth or precise flying. The integrated controller had a similar adjustable friction control for the collective power control (photo 2, app D), making small precise control inputs difficult with friction applied. The adverse characteristics of the sliding friction control were amplified in the integrated controller because more movements are required with the integrated controller (para 24) than with the conventional controls. The nonlinear control friction characteristics of the integrated controller are a shortcoming.

13. The integrated controller also had a force trim release switch incorporated in the hand grips which was unusable because the mechanics of the integrated controller, as described in appendix B, required that the force trim system be deactivated to prevent the pilot's control inputs from moving override springs rather than the desired controls. Without friction or force trim on the control system, the only force required to move the controls is the force required to overcome the initial breakout force (total force, including friction, required to initiate control movement) of at least 3.5 pounds. Once breakout force was applied, the control continued to move without any measurable force on the control. With force trim engaged, the control forces are as depicted in table 2. In comparison with the control forces of the conventional controls (ref 7, app A), the forces of the integrated controller were higher. The lack of a satisfactory force trim system for the integrated controller greatly increased pilot fatigue and is a shortcoming.

Table 2. Integrated Controller Control Forces.[1]

Control	Breakout Force (lb)	Force Gradient (lb/in.)
Longitudinal cyclic	3.4 fwd	3.4 fwd
	3.4 aft	2.8 aft
Lateral cyclic	3.0 left	9.7 left
	4.0 right	11.0 right

[1]Force trim ON.

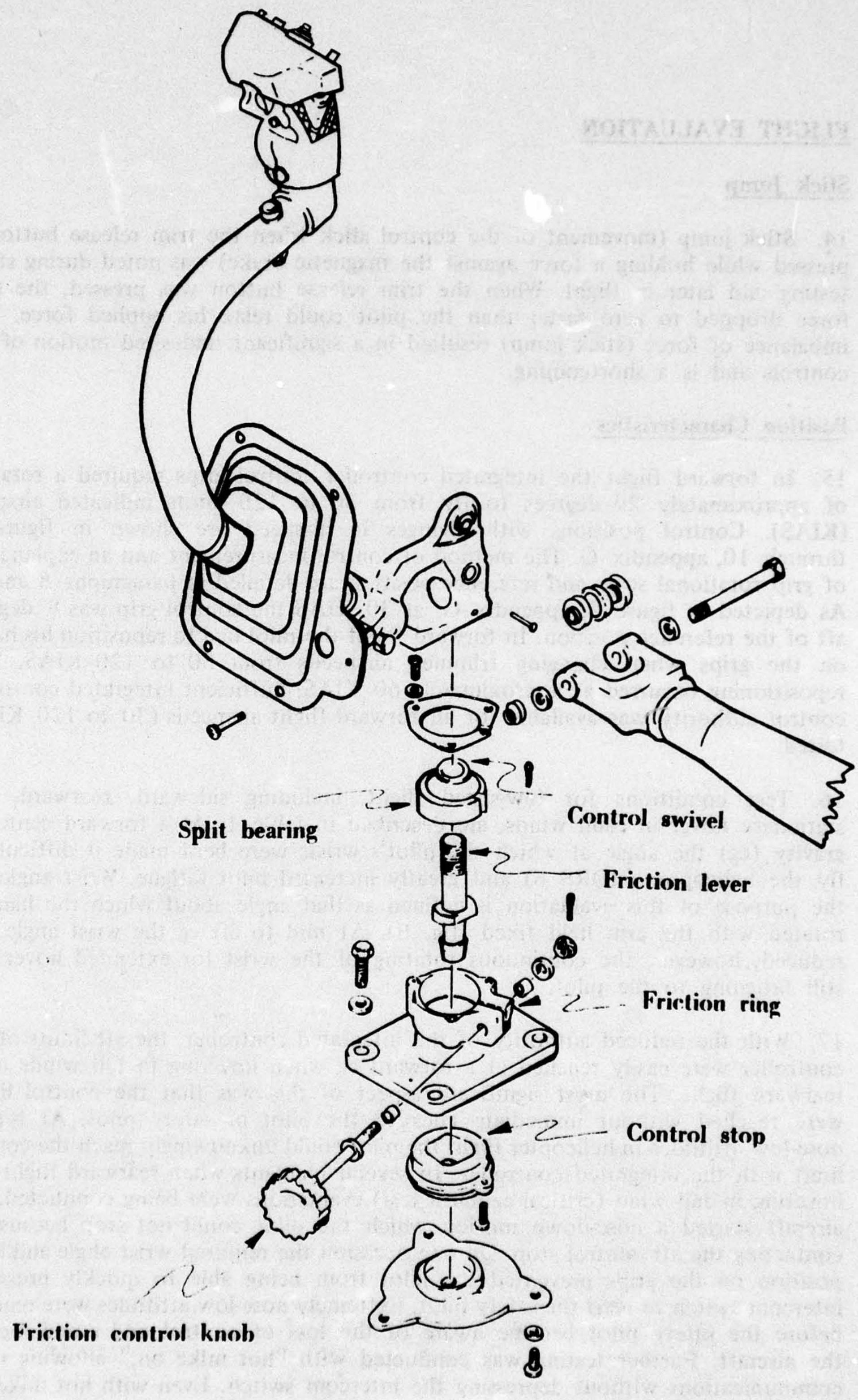


Figure A. Cyclic Stick and Friction Control.

FLIGHT EVALUATION

Stick Jump

14. Stick jump (movement of the control stick when the trim release button is pressed while holding a force against the magnetic brake) was noted during static testing and later in flight. When the trim release button was pressed, the trim force dropped to zero faster than the pilot could relax his applied force. The imbalance of force (stick jump) resulted in a significant undesired motion of the controls and is a shortcoming.

Position Characteristics

15. In forward flight the integrated controller control grips required a rotation of approximately 29 degrees to fly from 30 to 120 knots indicated airspeed (KIAS). Control positions with changes in airspeed are shown in figures 4 through 10, appendix G. The method of control measurement and an explanation of grip rotational scale and reference position are detailed in paragraphs 8 and 9. As depicted in figure 4, appendix G, at 30 KIAS the control grip was 8 degrees aft of the reference position. In forward flight the pilot had to reposition his hands on the grips when changing trimmed airspeeds from 30 to 120 KIAS. This repositioning occurred at approximately 60 KIAS. Sufficient integrated controller control authority was available for all forward flight airspeeds (30 to 120 KIAS) tested.

16. Test conditions for low-speed flight, including sideward, rearward, and stationary hover in calm winds, are described in table 1. At a forward center of gravity (cg) the angle at which the pilot's wrists were bent made it difficult to fly the helicopter (HQRS 6) and greatly increased pilot fatigue. Wrist angle for the purpose of this evaluation is defined as that angle about which the hand is rotated with the arm held fixed (fig. B). At mid to aft cg the wrist angle was reduced; however, the continuous rotating of the wrist for extended hover was still fatiguing to the pilot.

17. With the reduced authority of the integrated controller, the aft limits of the controller were easily reached at a forward cg when hovering in tail winds or in rearward flight. The most significant aspect of this was that the control limits were reached without immediate cues to the pilot or safety pilot. At typical nose-low attitudes in helicopter flight the pilot could unknowingly reach the control limit with the integrated controller. In several incidents when rearward flight and hovering in tail wind (critical azimuth test) evaluations were being conducted, the aircraft started a nose-down motion which the pilot could not stop because of contacting the aft control stop. On one occasion the required wrist angle and hand position on the grips prevented the pilot from being able to quickly press the intercom switch to alert the safety pilot. Extremely nose-low attitudes were reached before the safety pilot became aware of the loss of control and could recover the aircraft. Further testing was conducted with "hot mike on," allowing voice communications without depressing the intercom switch. Even with hot mike, on

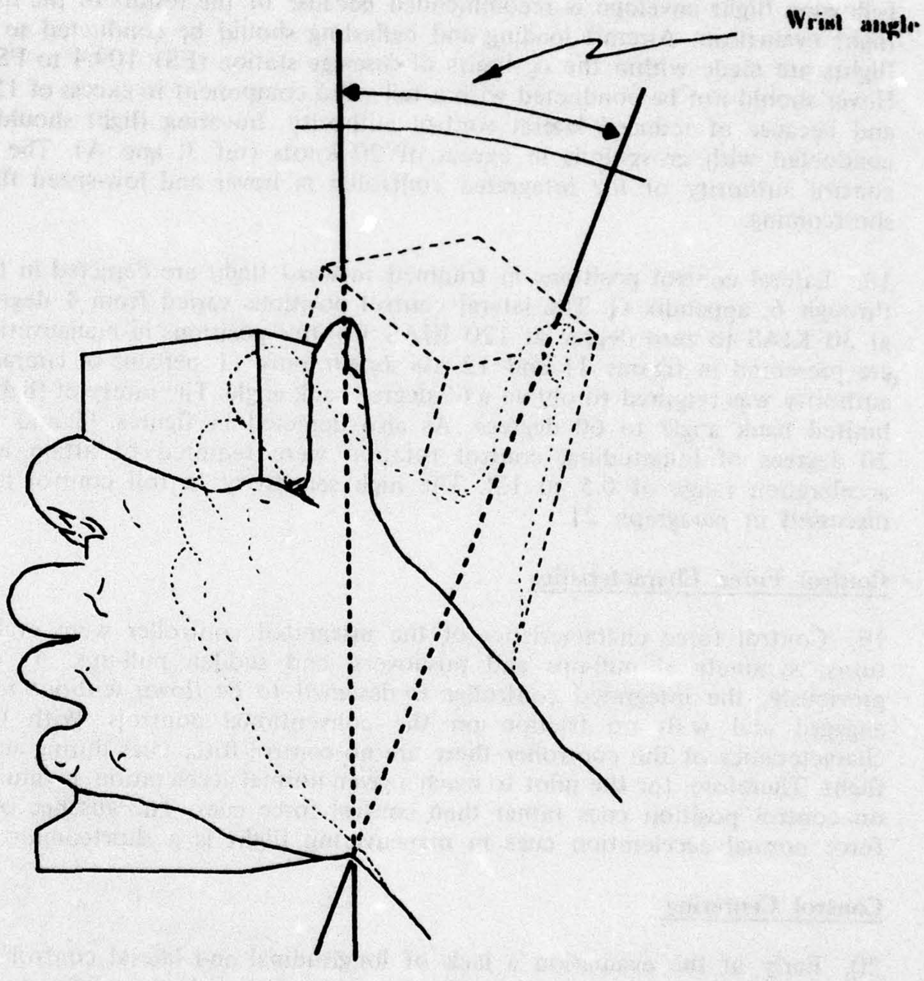


Figure B. Illustration of Pilot Hand Motion.

one occasion the nose pitched down and the aft control limit was reached so rapidly that a dangerously nose-low attitude was attained before the safety pilot recovered the aircraft. Prior to completion of the evaluation, microswitches which activated a warning lamp on the instrument panel to warn the pilot and safety pilot that a control limit had been reached were installed on the four cyclic stops. The following flight envelope is recommended because of the results of the low-speed flight evaluation. Aircraft loading and ballasting should be conducted so that all flights are made within the cg limits of fuselage station (FS) 109.4 to FS 111.0. Hover should not be conducted with a tail wind component in excess of 15 knots, and because of reduced lateral control authority, hovering flight should not be conducted with crosswinds in excess of 20 knots (ref 3, app A). The reduced control authority of the integrated controller in hover and low-speed flight is a shortcoming.

18. Lateral control positions in trimmed forward flight are depicted in figures 4 through 6, appendix G. The lateral control positions varied from 4 degrees right at 30 KIAS to zero degree at 120 KIAS. Control positions in maneuvering flight are presented in figures 11 and 12. As shown, only 11 percent of lateral control authority was required to obtain a 60-degree bank angle. The safety-of-flight release limited bank angle to 60 degrees. As also depicted in figures 11 and 12, only 20 degrees of longitudinal control rotation were required to attain a normal acceleration range of 0.5 to 1.8. The high sensitivity in roll control is further discussed in paragraph 21.

Control Force Characteristics

19. Control force characteristics of the integrated controller were evaluated in turns, symmetrical pull-ups and pushovers, and sudden pull-ups. As discussed previously, the integrated controller is designed to be flown without force trim engaged and with no friction on the conventional controls. With the force characteristics of the controller there are no control force cues during accelerated flight. Therefore, for the pilot to reach a given normal acceleration, he must depend on control position cues rather than control force cues. The absence of control force normal acceleration cues in maneuvering flight is a shortcoming.

Control Centering

20. Early in the evaluation a lack of longitudinal and lateral control centering (force trim ON) was determined. The lateral centering characteristics were greatly improved by reducing some internal friction in the control system; however, adverse centering characteristics of the longitudinal control still existed. The absence of positive longitudinal control centering is a shortcoming.

Control Sensitivity

21. Longitudinal and lateral control sensitivities (angular acceleration per unit of control displacement) were too high with the integrated controller. Control sensitivity for the integrated controller is presented in figures 13 through 17,

appendix G. A 1-inch longitudinal input on the conventional cyclic control produces a pitch acceleration of 11 deg/sec^2. A 0.1-inch angular rotation of the integrated controller produces the same 11-deg/sec^2 pitch acceleration. The oversensitive controls severely degraded flying qualities of the OH-58A and greatly increased pilot workload, particularly in performing tasks requiring small precise control inputs, such as in a hover. In nap-of-the-earth high-speed flight where rapid roll rates and pitch attitude changes were required, the high sensitivity of the longitudinal and lateral control was satisfactory and in some aspects desirable. However, for all maneuvers tested except nap-of-the-earth flight, the longitudinal and roll control sensitivity was too high and is a deficiency in the integrated control system.

Control Harmony

22. Control harmony for the purpose of this evaluation is defined as the compatibility of the control forces, sensitivities, and displacements. The integrated controller exhibited poor control harmony between the pitch and roll controls and the collective control. Inputs to one control resulted in advertent inputs to another control. As previously discussed in paragraph 21, control sensitivity was high in pitch and roll; however, collective control sensitivity was too low, and therefore large collective control inputs were required to obtain desired power changes. When collective pitch changes were made, inadvertent roll and pitch inputs greatly increased pilot workload. The poor control harmony is a deficiency.

MISSION MANEUVERS

23. The primary approach to determine the conceptual feasibility of the integrated controller design was to evaluate the capability to perform normal mission maneuvers. The evaluation included all maneuvers authorized in the operator's manual (ref 9, app A) within the constraints imposed by the safety-of-flight release. The evaluation of the integrated controller's feasibility was essentially to answer the question: How well can the helicopter be expected to complete the operational objectives of its mission with the integrated controller as the primary control system?

24. As discussed in paragraphs 26 through 31, the pilot could accomplish all the authorized maneuvers using the integrated controller. However, the pilot workload required to complete the maneuvers was so much greater with the integrated controller than with conventional controls that, in its present design, the pilot could not effectively perform operational missions. The system in its present design was therefore not feasible for operational use. However, because of the poor control harmony and sensitivities that were built into this particular system which may or may not be inherent in an integrated controller, the conceptual feasibility could not be evaluated.

Hover

25. The most difficult tasks during the evaluation were hovering and landing from a hover. The control grips initially designed for the controller (photo 2, app D) were installed during the early phases of the evaluation. The helicopter could not be hovered satisfactorily with these grips. Inputs in any one control resulted in unintentional inputs in the other two controls, which was a particular problem when the pilot intentionally made power changes and inadvertent large longitudinal pitch changes resulted. The second control design (photo 1) reduced this problem on grip redesign so that the rotation of the hand was about the axis of rotation of the longitudinal control and also the point of collective force application was perpendicular to the longitudinal axis control. The redesigned control grips were installed after the sixth flight of the test program. The only engineering flight tests that had been completed prior to installation of the new grips were static longitudinal and static lateral-directional tests. These tests were later repeated with the redesigned grips. Test results presented in this report are for the redesigned grips; however, there were essentially no differences in static longitudinal and static lateral-directional test results between the original and redesigned grips. After the control grip design change, the hover task was improved but pilot workload was still much higher with the integrated controller than with conventional controls. The quantitative pilot workload evaluation was made after the pilot had obtained approximately 20 hours flight time with the integrated controller.

26. A comparison of pilot workload in a hover was made between the integrated controller and standard controls. A limited quantitative evaluation was made by recording the amplitude and number of control reversals per unit of time. This evaluation technique is discussed in more detail in appendix F. The comparison was made with the pilot first using the standard controls, then the integrated controller. The change to the integrated controller was made immediately after recording the hover with conventional control, thereby providing essentially the same aircraft cg and weight and atmospheric conditions. A comparison of pilot workload in a hover between the conventional controls and the integrated controller is presented in figure 18, appendix G, and summarized in table 3. There was a significant increase in reversal frequency and amplitude in lateral and longitudinal controls with the integrated controller. In collective power control the frequency of reversals was significantly increased; however, in amplitude there was a slight decrease with the integrated controller. Throughout the evaluation it was qualitatively noted that pilot workload was equal to or greater with the integrated controller than with conventional controls; the greatest workload increase was in a hover.

Table 3. Pilot Workload In a Hover.[1]

Integrated Controller Compared to Conventional Controls	Control Reversals (%)	Control Amplitude (%)
Longitudinal cyclic increase	15	69
Lateral cyclic increase	42	32
Collective change	54 (increase)	4 (decrease)

[1]Data were reduced from 30-second time histories.

27. At the end of the evaluation, three additional test pilots flew the test helicopter using the integrated controller. Two of the pilots flew for 1.5 hours and the third for 2 hours. Prior to flying the test aircraft, each pilot received approximately 3 hours in the GAT-II simulator equipped with an integrated controller system (para 1). Each pilot received approximately 20 minutes of control familiarization at altitude before attempting to hover the helicopter. At the end of 1.5 hours one pilot could not satisfactorily hover or land from a hover with the integrated controller. After a similar time period, a second pilot could not maintain a hover over a designated point on the ground or land without landing hard and bouncing the helicopter. The third pilot, after 2 hours, could maintain a satisfactory hover and could make landings that would be considered marginally acceptable with conventional controls. All three pilots tended to start pilot-induced oscillations, both in the longitudinal control and the collective control, while hovering. This can be primarily attributed to the poor control harmony discussed in paragraph 22. It was concluded from these limited tests that the flying qualities were degraded and pilot workload significantly increased with the integrated controller in a hover and when making landings from a hover. The increase in pilot workload in a hover with the integrated controller is a deficiency. The pilot-induced oscillation tendency during a hover is a shortcoming.

Takeoffs and Landings

28. Two takeoff techniques were evaluated, the first being a takeoff from a hover with an immediate transition into forward flight. The second technique was accomplished by lifting to a hover over the takeoff site and then transitioning to forward flight. In the takeoff from a hover, the most difficult aspect was obtaining the stabilized hover prior to starting the takeoff. The takeoff was accomplished with little, if any, increase in difficulty over that with a conventional control. A tendency for pilot-induced oscillations of the collective pitch control was noted on the climb-out. The pilot-induced oscillation tendency during takeoff is a shortcoming.

29. In the initial lift-off from the ground, the pilot tended to not rotate the longitudinal control sufficiently aft and instead attempted to raise the nose of the helicopter by pulling aft on the collective power control, which only increased the nose-down pitching moment of the helicopter. The three test pilots who flew the aircraft at the end of the project all had the same problem on lift-off. This was corrected after practice, which varied with each pilot; generally, two or three takeoffs were necessary before the lift-off technique was considered satisfactory.

30. Landings from a hover with the integrated controller were extremely difficult and required high pilot workload (HQRS 7). The most difficult aspect was the coordination of collective power, roll, and longitudinal control. As the collective power control was pushed forward, longitudinal control had to be rotated aft and small lateral control movements made to correct for small roll oscillations of the helicopter. Landing with one hand could only be accomplished after much practice and only under ideal conditions, *ie*, calm winds and mid to aft cg loadings. Slope landings had the same characteristics as landing from a hover, in addition to the limited control authority in the controller design. Slope landings were limited to slopes of approximately 6 degrees because control limits were reached at this point. The high pilot workload required in landing from a hover is a deficiency.

31. Running and autorotational landing characteristics were also evaluated. Running landings with the integrated controller were accomplished with a minimal increase in pilot workload (HQRS 3). Most of this increase was a result of the high sensitivity in roll and pitch. Autorotational landings were made from a hover and from forward flight. Poor control harmony reduced the quality of the autorotations; however, safe autorotational landings could be made with the integrated controller.

COCKPIT INTERFACE

32. The most significant aspect in interfacing cockpit and controller was the absence of adjustability of controller position relative to the pilot. The OH-58A cockpit incorporates nonadjustable seats and the present design of the integrated controller does not permit adjustment. The test pilot (73 inches in height) had to fly with the seat back cushion removed to prevent being too close to the controller and to allow sufficient clearance between the controller grips and the pilot's knees. The inability to adjust controller position relative to the pilot is a deficiency.

33. The controller position hampered entry into and egress from the cockpit. To get into the left seat, the pilot had to first balance on one leg and then move the other leg around the control, with little room between controller and center pedestal. As depicted in photo 3, appendix D, a control linkage was exposed, hampering entry into the cockpit; the control linkage could easily be damaged during entry. The exposed control linkage is a shortcoming.

34. Two arm rests (photo 3, app D) were added to provide arm support for reducing pilot fatigue and providing the support necessary for one-handed flight. The design and installation of the arm rest was an enhancing characteristic of the cockpit.

35. The redesigned controller hand grips were too large for the pilot to comfortably grip. Flying with a grip this size was extremely fatiguing to the pilot. The excessively large grip is a deficiency.

36. The present cockpit arrangement does not incorporate provisions for left-side throttle control. As in a standard OH-58A, provisions for rpm beep trim, landing light, and start controls are not incorporated for the left seat. However, if the integrated controller is to be used for primary controls these provisions must be incorporated. The safety pilot (right side) could not transmit on the radio without pushing the radio control switch on the cyclic stick. This contact with the cyclic was felt by the pilot and in some cases resulted in unintentional control inputs. A floor-mounted radio control switch should be incorporated to eliminate the requirement for the safety pilot to use the cyclic radio switch when the integrated controller is used to fly the helicopter.

SUDDEN ENGINE FAILURES

37. Simulated sudden engine failure tests (throttle chops) were conducted in level flight and climbs at the airspeeds detailed in table 1. Torque settings varied from 37 to 86 psi. The helicopter was trimmed at a given flight condition and the throttle was abruptly closed to the flight-idle position to simulate a sudden engine failure. The flight controls were held fixed as long as possible (up to a maximum of 2 seconds) to simulate the normal delay in pilot reaction time following an actual engine failure.

38. Generally, the reaction of the OH-58A following a throttle chop was characterized by a slight nose-up pitch during the first second, followed by a substantial nose-down pitching motion, in addition to a left yaw and left roll tendency. The resultant pitch, roll, and yaw rates varied with airspeed and power settings. Because of the nose-down pitching, considerable aft cyclic control was required to return to a normal autorotational attitude. The combination of aft rotation of longitudinal control and forward movement of collective power control required increased pilot compensation over that of the conventional control but was accomplished without a significant degradation of autorotational entry characteristics. Some pilot-induced oscillation of collective power control was noted in the autorotation; however, desired autorotational rotor speed could be maintained with moderate pilot compensation (HQRS 5). Pilot-induced oscillations during autorotation are a shortcoming.

39. **Autorotational entries with the integrated controller required an increase in pilot compensation over those with the standard controls. However, safe autorotational entries could be made with the integrated controller under all conditions listed in table 1. An improvement in control harmony, discussed in paragraph 22, should reduce pilot workload in autorotational entry and descent.**

CONCLUSIONS

GENERAL

40. The following conclusions were reached upon completion of the integrated controller system evaluation:

a. The standard flight controls installed on the right side operated satisfactorily with the integrated flight control system installed (para 11).

b. Within the recommended safe flight envelope the OH-58A helicopter with integrated controller can be safely flown for further USAHEL testing (para 17).

c. Because of the deficiencies and shortcomings found during this evaluation, the feasibility of the integrated controller concept could not be evaluated (para 24).

d. With the present integrated controller design, the pilot workload in all maneuvers was equal to or greater with the integrated controller than with conventional controls (para 26).

e. Five deficiencies and eight shortcomings were identified.

DEFICIENCIES

41. The following deficiencies of the integrated controller installed on the JOH-58A helicopter were identified:

a. Too high longitudinal and roll control sensitivity (para 21).

b. Lack of harmony in longitudinal, lateral, and collective pitch control (para 22).

c. High pilot workload (paras 27 and 30).

d. Inability to change pilot position relative to the control (para 32).

e. Too large grip size (para 35).

SHORTCOMINGS

42. The following shortcomings of the integrated controller installed on the JOH-58A helicopter were identified:

a. Nonlinear control friction characteristics (para 12).

b. Lack of a satisfactory force trim system (para 12).

c. Excessive stick jump (para 14).

d. Reduced control authority (para 17).

e. No control force/normal acceleration cues in maneuvering flight (para 19).

f. Poor longitudinal centering characteristics (para 21).

g. Pilot-induced oscillation tendencies in hover, on takeoff, and during autorotation (paras 27, 28, and 38).

h. Exposed collective linkage for the integrated controller (para 33).

RECOMMENDATIONS

43. The deficiencies should be corrected prior to future engineering flight evaluation of the integrated controller.

44. The shortcomings should be corrected.

45. A floor-mounted radio control switch should be installed on the right side of the cockpit (para 36).

APPENDIX A. REFERENCES

1. Letter, AVSCOM, AMSAV-EQI, 6 October 1975, subject: Integrated Controller Evaluation, OH-58 Project No. 75-24.

2. Letter, AVSCOM, AMSAV-EQI, 16 January 1976, subject: Safety-of-Flight Release (SOFR) - OH-58A Helicopter with Integrated Controller Installation.

3. Message, AVSCOM, AMSAV-EQI, 0171910, subject: USAAEFA Project 75-24, OH-58 Integrated Controller Evaluation Test Plan.

4. Letter, AVSCOM, AMSAV-EQI, 19 January 1976, subject: Amendment to Safety-of-Flight Release (SOFR) - OH-58A Helicopter with Integrated Controller Installation.

5. Message, AVSCOM, AMSAV-EQI, 02232121, subject: Amendment to Safety-of-Flight Release (SOFR) - OH-58A Integrated Controller Installation.

6. Message, AVSCOM, AMSAV-EQI, 0491656, subject: Amendment to Safety-of-Flight Release (SOFR) - OH-58A Helicopter with Integrated Controller Installation.

7. Final Report, US Army Aviation Systems Test Activity, Project No. 68-30, *Airworthiness and Flight Characteristics Test, Production OH-58A Helicopter Unarmed and Armed with XM27E1 Armament Subsystem, Stability and Control*, October 1970.

8. Test Plan, USAAEFA, Project No. 75-24, *OH-58A Integrated Controller Evaluation*, January 1976.

9. Technical Manual, TM 55-1520-228-10, *Operator's Manual, Army Model OH-58A Helicopter*, 7 September 1972.

APPENDIX B. INTEGRATED CONTROLLER SYSTEM DESCRIPTION

GENERAL

1. The integrated controller combines conventional helicopter cyclic and collective controls into a control element capable of being operated with one hand. The integrated controller has approximately 65 percent of the control authority of the conventional cyclic control. This safety feature is accomplished through the use of three override springs, one each for longitudinal, lateral, and collective control inputs. The safety pilot can override the integrated controller with the conventional controls. The override capability was verified during control system characteristics ground tests (para 9, Results and Discussion).

2. The integrated controller consists of a vertical column which provides collective control inputs to the swashplate (fig. 1); two hand grips on the opposing lateral sides of the vertical column provide for the lateral and longitudinal inputs to the swashplate (fig. 1). The hand grips may be operated together or independently.

LONGITUDINAL

3. Longitudinal pitch control is achieved by the rotation of either or both of the hand grips about the control rod extending through the vertical column (fig. 2). Rotating the grips (top of grip) forward inputs a nose-down pitch moment to the aircraft. Rotating the grips (top of grip) rearward inputs a nose-up pitch moment to the aircraft. The input is transferred to a push-pull rod (fig. 2), a bell crank, and to another push-pull rod (fig. 3) through an override spring (figs. 4 and 5) to a wishbone connection which joins the conventional longitudinal control to the integrated longitudinal control.

4. The integrated controller hand grips rotate a total of 55.32 degrees in the longitudinal direction. This rotation moves the conventional longitudinal cyclic 8.34 inches. The conventional cyclic has 12.27 inches of full travel; thus, the integrated controller has 68 percent full authority.

LATERAL

5. Lateral roll control is achieved by rotating the hand grips together or independently about a pivot point in the vertical plane (fig. 2). Clockwise rotation of the grips produces a right roll moment to the aircraft. Counterclockwise rotation produces a left roll moment to the aircraft. The rotation of the grips about the

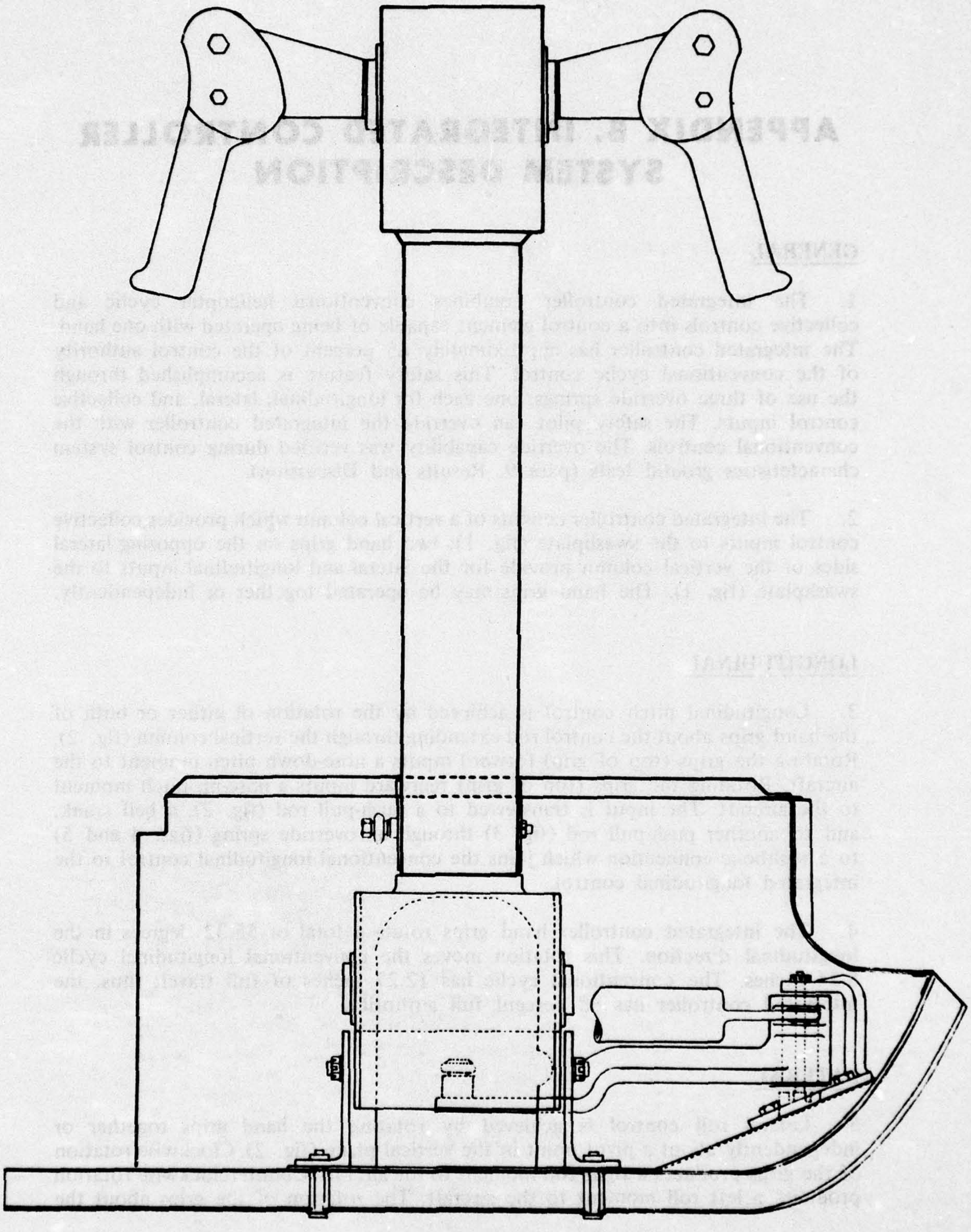


Figure 1. Integrated Controller.

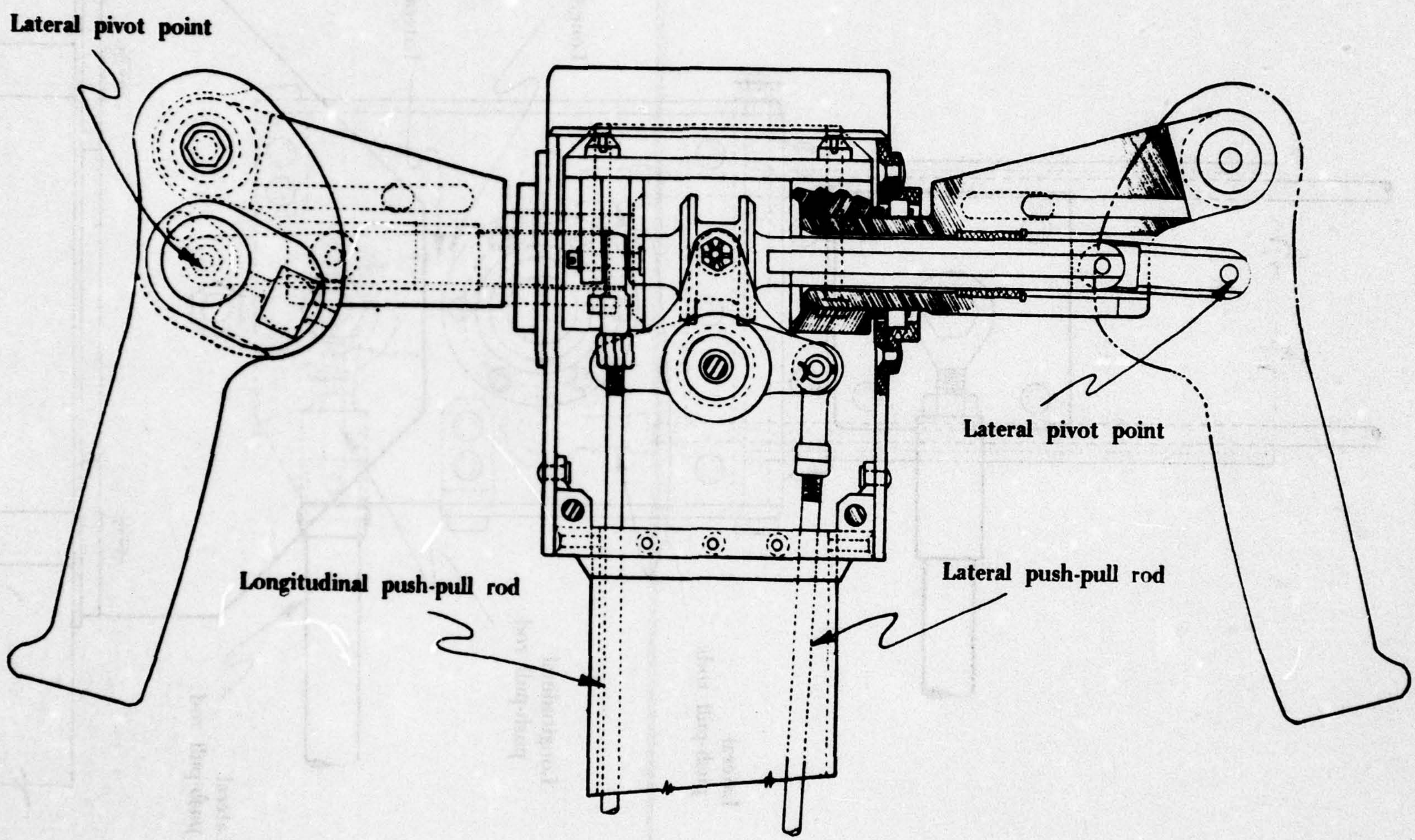


Figure 2. Integrated Controller Handgrips.

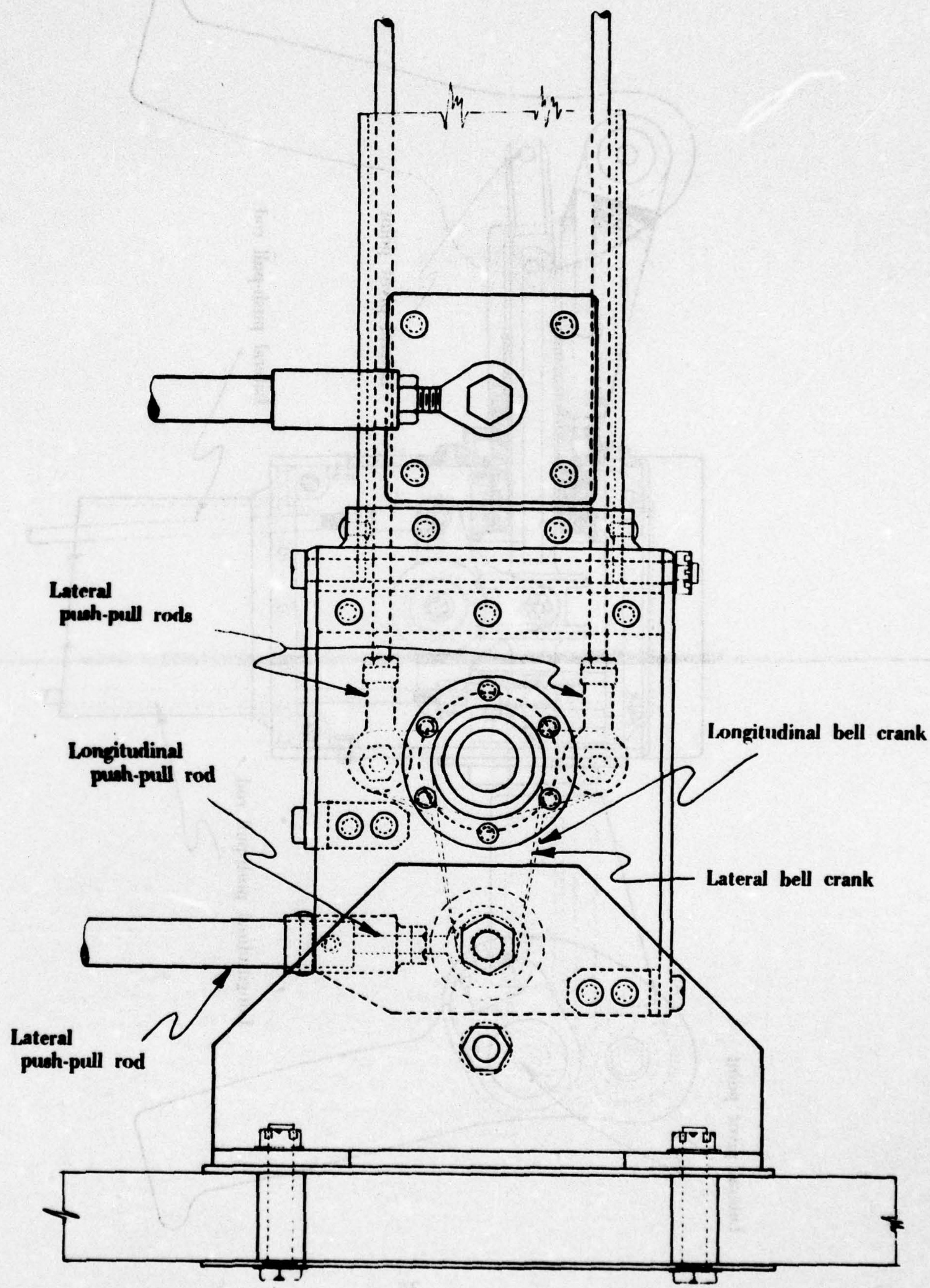


Figure 3. Integrated Controller Mechanical System.

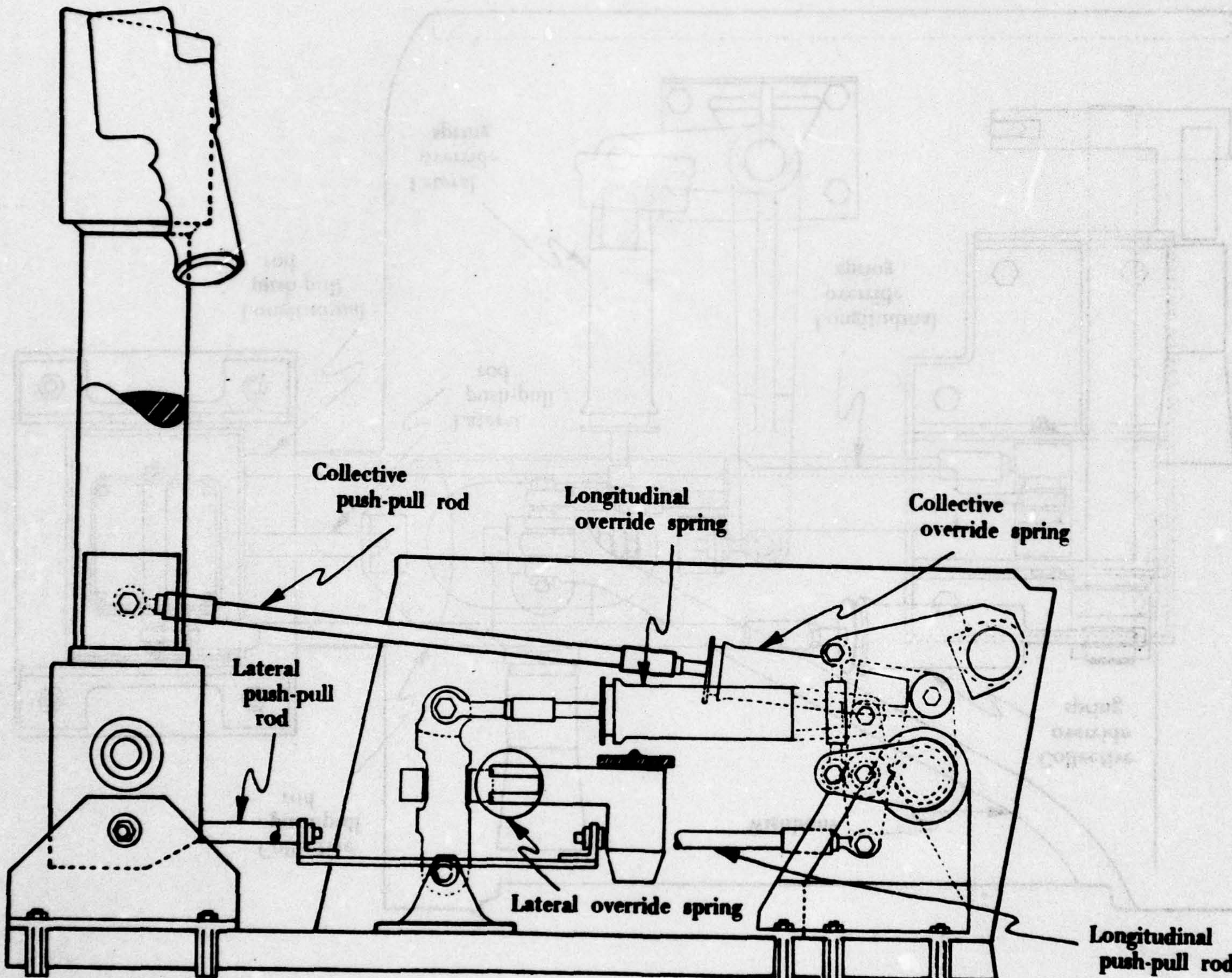


Figure 4. Cutaway Side View, Integrated Controller.

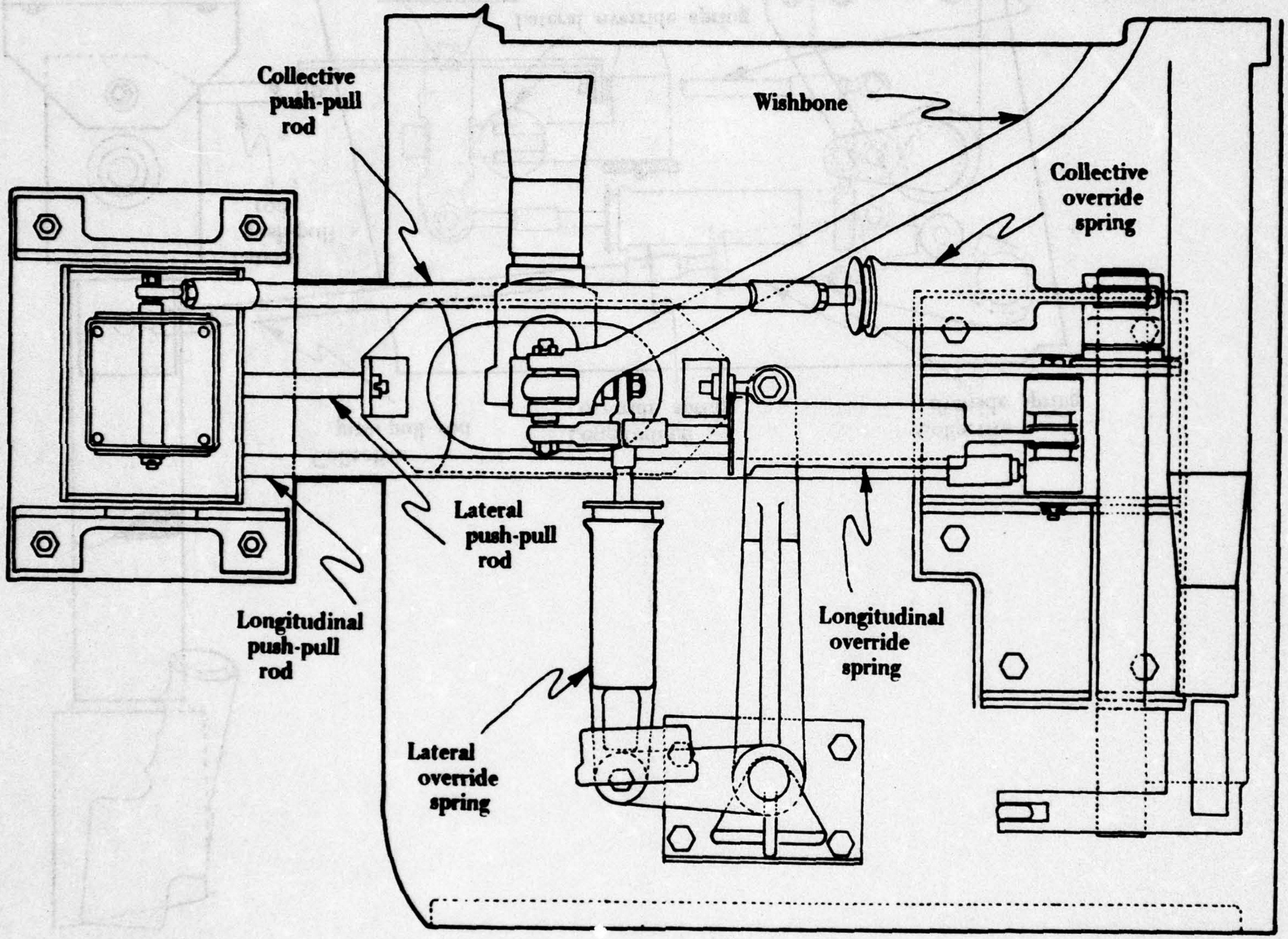


Figure 5. Integrated Controller Override Springs and Control Rods.

pivot point transfers the input to a bell crank and push-pull rod (fig. 2). This input is further transferred to a second bell crank and push-pull system (fig. 3) through an override spring (figs. 4 and 5) to a wishbone system which joins the conventional cyclic and integrated controller lateral controls.

6. The integrated controller rotates laterally a total of 46 degrees. Full rotation will move the conventional cyclic 6.05 inches in the lateral direction. The conventional cyclic full travel is 9.4 inches laterally; thus, the integrated controller has 64 percent full authority in the lateral direction.

COLLECTIVE

7. Collective pitch control is achieved with the integrated controller by pushing or pulling the vertical column (fig. 1) with either or both of the hand grips. The collective-down position is accomplished with the vertical column full forward. Pulling the column rearward increases collective pitch. Pushing or pulling the collective column acts upon a push-pull rod (fig. 4) which is connected to the collective override spring (figs. 4 and 5). The control movement then goes into a wishbone connection which couples the conventional collective to the integrated controller collective.

8. Full integrated controller vertical column movement is 8.05 inches. This displaces the conventional collective 10 inches. The conventional collective full travel is 10.8 inches and the integrated controller has 93 percent control authority.

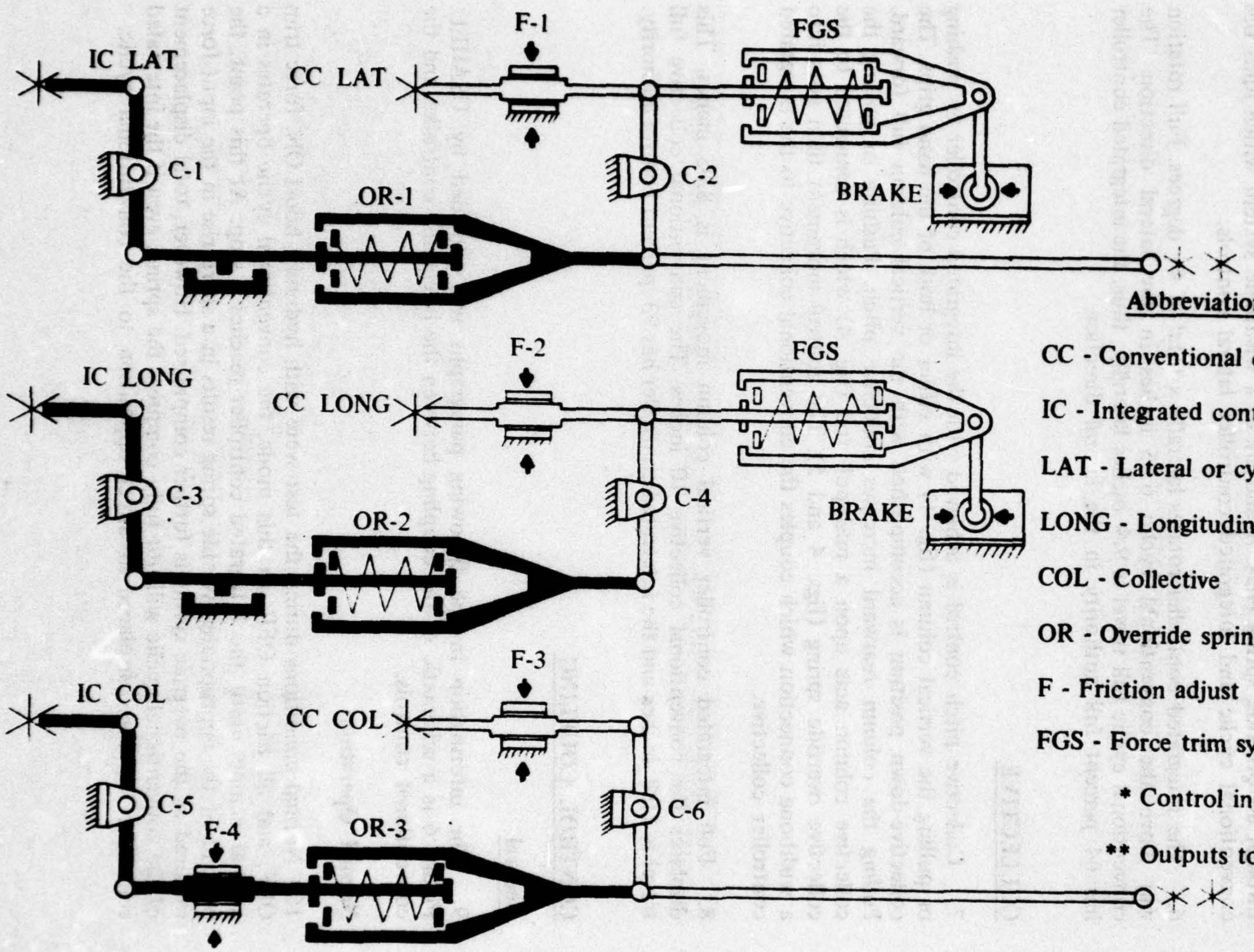
CONTROL COUPLING

General

9. The information in the following paragraphs was provided by USAHEL. Figure 6 is a schematic of the coupling between the integrated controller and the conventional controls.

Normal Operation:

10. Normal conditions during the test were with hydraulic boost ON, force trim OFF, and all friction OFF. In this mode, the conventional cyclic operates in a normal manner until the integrated controller reaches a stop. At this point, the preload of the appropriate override spring results in a sharp rise in the input force required as the override spring is further compressed. However, total displacement of the conventional cyclic will not fully compress the spring, even if the integrated controller has been displaced in direct opposition to the conventional cyclic.



Abbreviations

CC - Conventional control

IC - Integrated control

LAT - Lateral or cyclic roll axis

LONG - Longitudinal or cyclic pitch axis

COL - Collective

OR - Override spring

F - Friction adjust

FGS - Force trim system gradient spring

* Control inputs

** Outputs to mixer and servos

Figure 6. Conventional and Integrated Control Coupling Schematic.

11. The conventional collective operates in a normal manner throughout its entire travel. Total compression of the override spring occurs only at the very limits of travel when the integrated controller collective and the conventional collective are in direct opposition.

12. In the normal mode of operation, normal control inputs made on the integrated controller cyclic or collective stay below the override spring preload levels and give the effect of being hard-coupled to the conventional controls from stop to stop. When the integrated controller reaches any of its four cyclic stops, a microswitch is activated which alerts the safety pilot to that condition by a warning light on the forward glare shield.

Force Trim:

13. When the hydraulic and force trim are ON and all friction OFF, the force trim system gradient spring (FGS) and its associated brake is active. When the brake is locked, any movement of bell crank C-2 or C-4 is resisted by the FGS. The required preload levels on the override springs are such that with force trim ON, the FGS gradients build up rapidly as an input is made on the integrated controller and control centering cannot be maintained. These gradients, except for a small initial increment, exceed the override spring preloads and pilot inputs are overridden by the FGS. When the force trim is ON, the pilot, in effect, flies the override springs instead of the aircraft.

Friction:

14. With the hydraulic boost ON, force trim OFF, no friction on the conventional controls, and friction applied to the integrated controller, the same results occur as explained in paragraph 13. Friction resists displacement of bell cranks C-2 or C-4 and the override springs are displaced instead of the swashplate. When light friction is applied to F-4, inputs on the conventional collective initially exceed the preload on override spring 3, causing the spring to displace until it overcomes the static drag at F-4. This causes the integrated controller vertical column to "stick" until the friction force is overcome by the spring; the vertical column then "jumps" until it "catches up" to the conventional collective. When the aircraft is flown by the safety pilot, the jump of the vertical column causes a feedback.

Hydraulics:

15. With force trim OFF, all friction OFF, and the hydraulic boost OFF, the control inputs required on the integrated controller are of such a magnitude that the integrated controller "flies" the override springs instead of the aircraft. Boost-off operation of the conventional controls is characteristic of boost-off operation in a standard OH-58A except for the additional force gradient added by the override springs when the integrated controller reaches limit stops.

APPENDIX C. INSTRUMENTATION

1. The data acquisition system employed on the JOH-58A helicopter incorporated a CEC Model 5-114-P3-18, 18-channel oscillograph to record flight parameters. A block diagram of the data acquisition system is presented in figure 1.

2. The following parameters were recorded from calibrated sensitive test instrumentation:

Pilot Panel

Airspeed
Altitude
Outside air temperature
Rotor speed
Engine torque
Turbine outlet temperature
Gas producer speed
Attitude (ship's system)

Safety Pilot Panel

Event switch
Record switch
Stop switch
Run number

3. The following parameters with ranges indicated were recorded on the oscillograph:

Longitudinal cyclic stick position: Buffalo position transducer, Model 017. Mounted beneath the pilot seat. Range: Zero to 100 percent.

Lateral cyclic stick position: Buffalo position transducer, Model 017. Mounted beneath the pilot seat. Range: Zero to 100 percent.

Collective stick position: Buffalo position transducer, Model 017. Mounted beneath the copilot seat. Range: Zero to 100 percent.

Pitch attitude: Electronic Specialties gyro, Model 5049A. Mounted on instrumentation package in passenger compartment. Range: +30 degrees to -30 degrees.

Roll attitude: Electronic Specialties gyro, Model 5049A. Same gyro as pitch attitude, but using roll axis. Range: +40 degrees to -40 degrees.

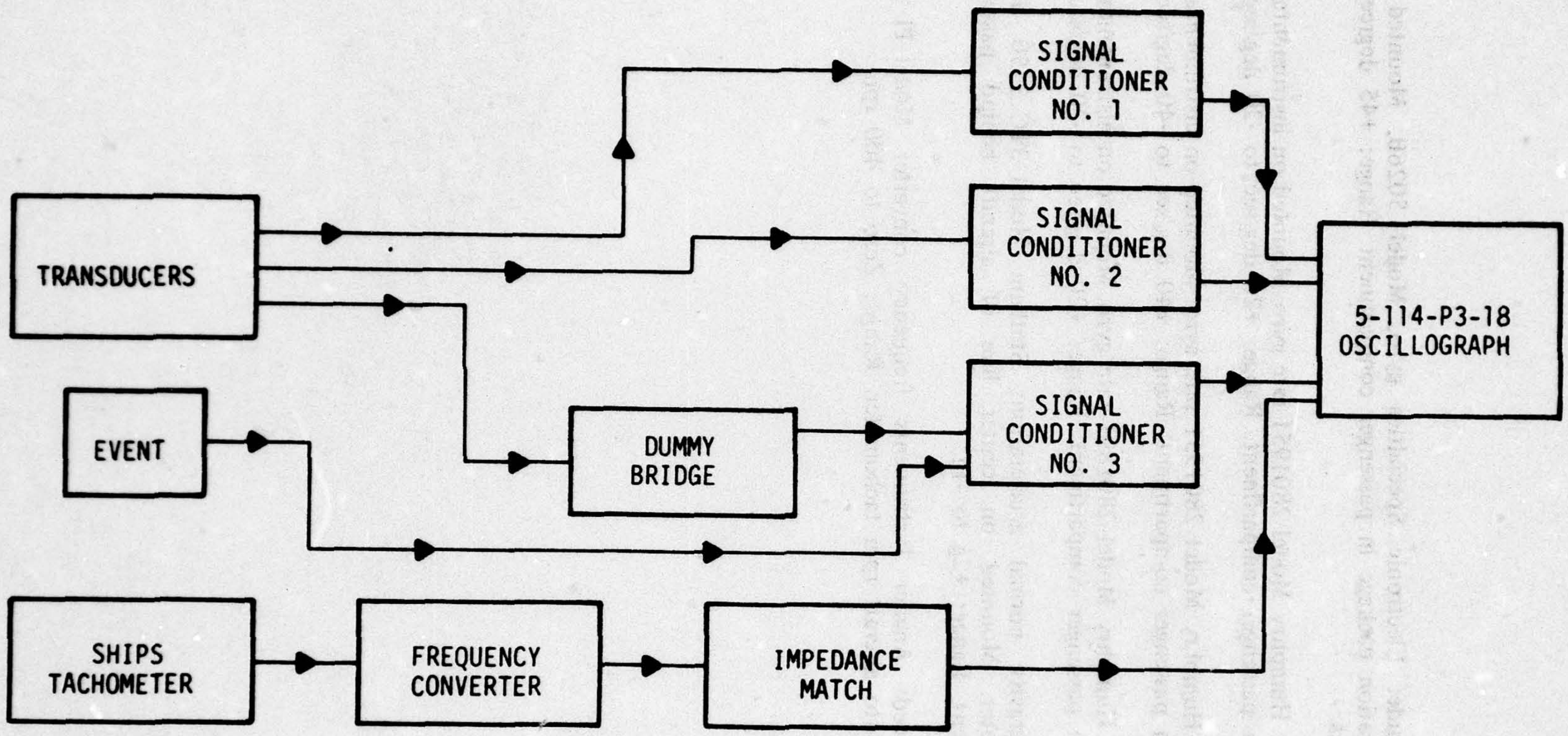


Figure 1. Data Acquisition System Schematic.

Yaw attitude: Electronic Specialties gyro, Model 5026B. Mounted on instrumentation package in passenger compartment. Range: +45 degrees to -45 degrees.

Pitch rate: Humphry Model 2801951 rate gyro. Mounted on instrumentation package in passenger compartment. Range: +20 deg/sec to -20 deg/sec.

Roll rate: Humphry Model 2801951 rate gyro. Mounted on instrumentation package in passenger compartment. Range: +40 deg/sec to -40 deg/sec.

Yaw rate: Humphry Model 2801891 rate gyro. Mounted on instrumentation package in passenger compartment. Range: +20 deg/sec to -20 deg/sec.

Center-of-gravity normal acceleration: Statham Model 3TC 3350 linear accelerometer. Mounted on center line of aircraft behind passenger compartment. Range: +2g to -1g.

Rotor speed: Anader Instruments frequency converter Model PI 375. Plumbed into aircraft rpm tachometer. Range: Zero to 400 rpm.

APPENDIX D. PHOTOGRAPHS

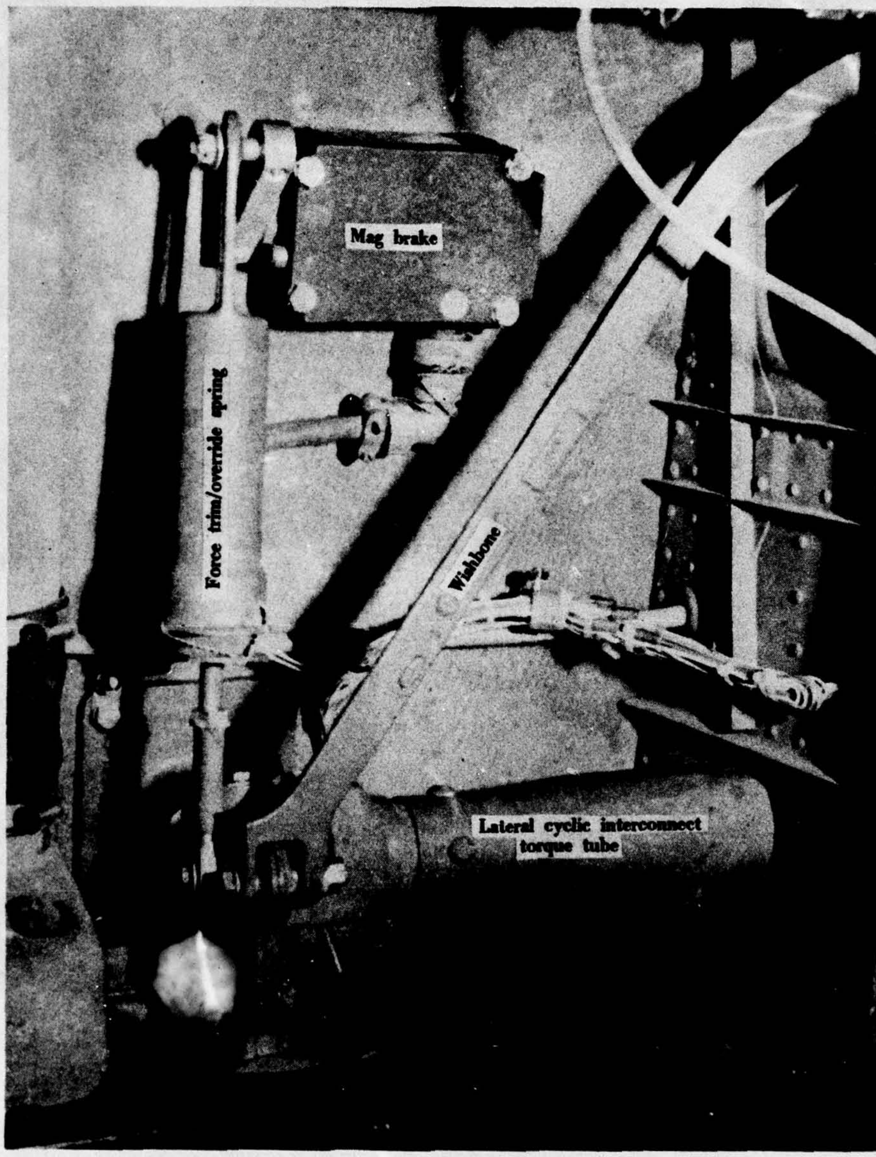


Photo 1. Force Trim Override System.

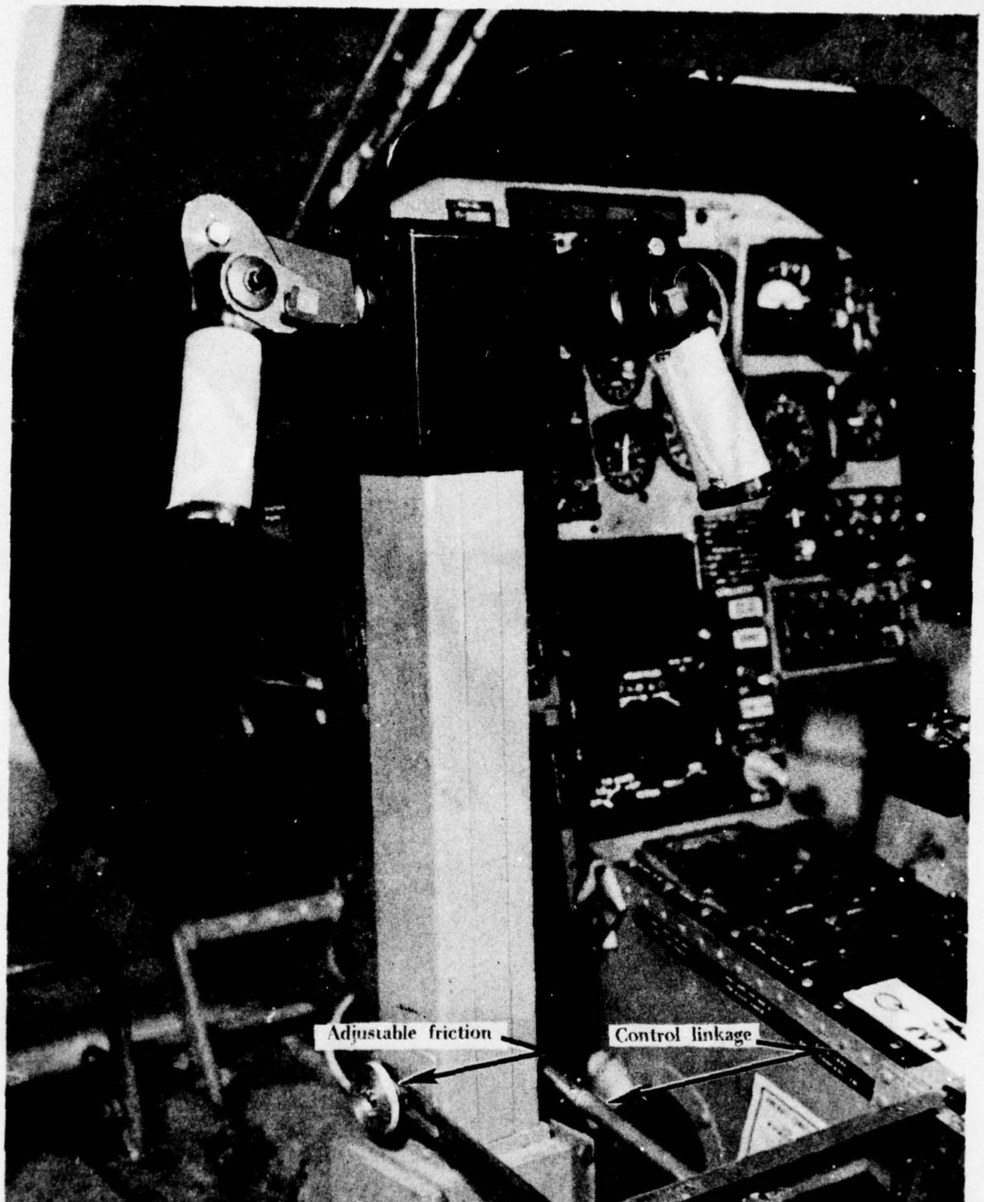


Photo 2. Integrated Controller With Original Hand Grips.

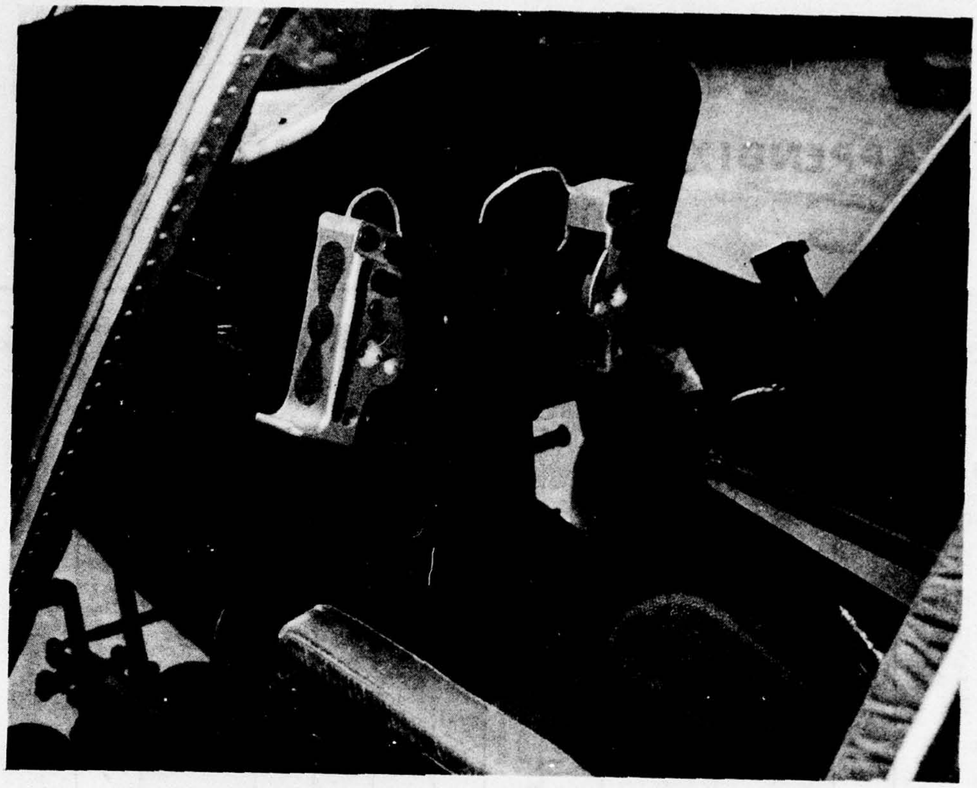
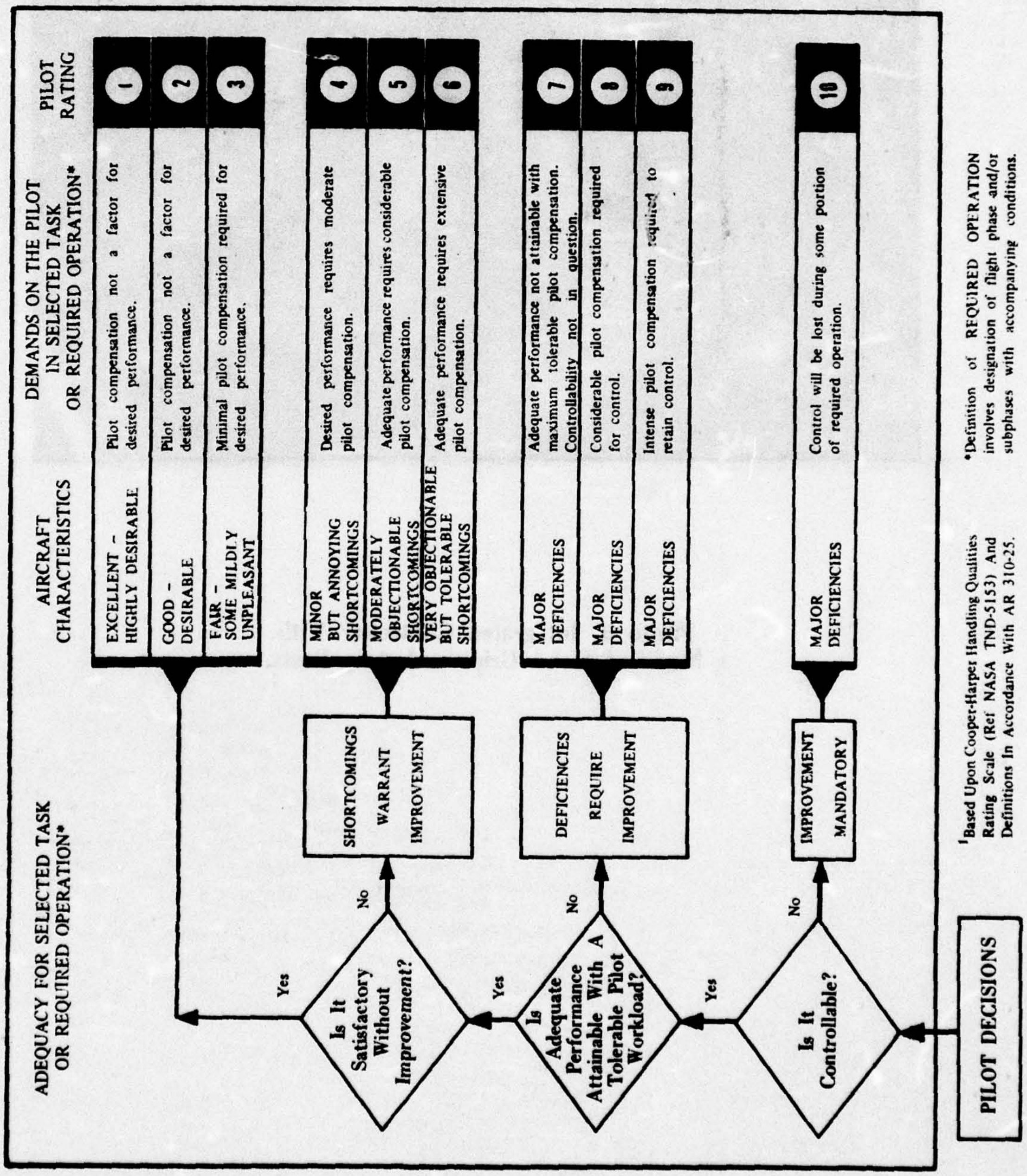


Photo 3. Integrated Controller With Modified Hand Grips and Arm Rests.

APPENDIX E. HANDLING QUALITIES RATING SCALE



[1]Based Upon Cooper-Harper Handling Qualities Rating Scale (Ref NASA TND-5153) And Definitions In Accordance With AR 310-25.

*Definition of REQUIRED OPERATION involves designation of flight phase and/or subphases with accompanying conditions.

APPENDIX F. DATA ANALYSIS METHODS

The amplitude and number of control reversals per unit time for each control (collective, lateral, and longitudinal cyclic position) during hover were analyzed to provide statistical data on pilot workload during this task. This task was flown first with the conventional controls and immediately repeated using the integrated controller, with pilot control movements recorded on the oscillograph. It is postulated that pilot workload can be qualified by recording the number of times a control was reversed in a given deflection band or zone per unit time. Each zone being 1 percent of full travel of the control, an example is depicted in figure 1.

APPENDIX G. TEST DATA

INDEX

Figure	Figure Number
Conventional vs Integrated Control Positions	1 through 3
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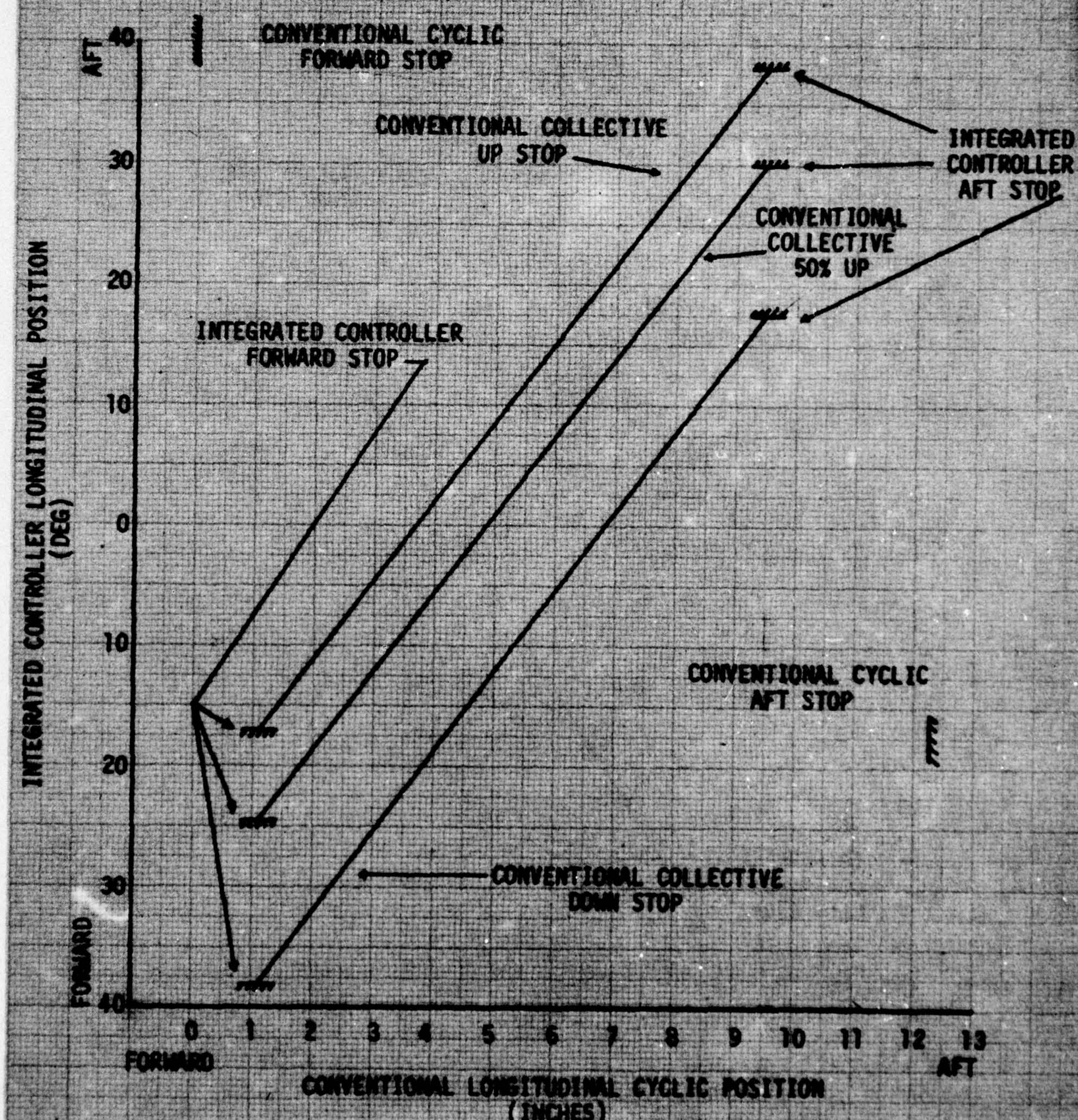
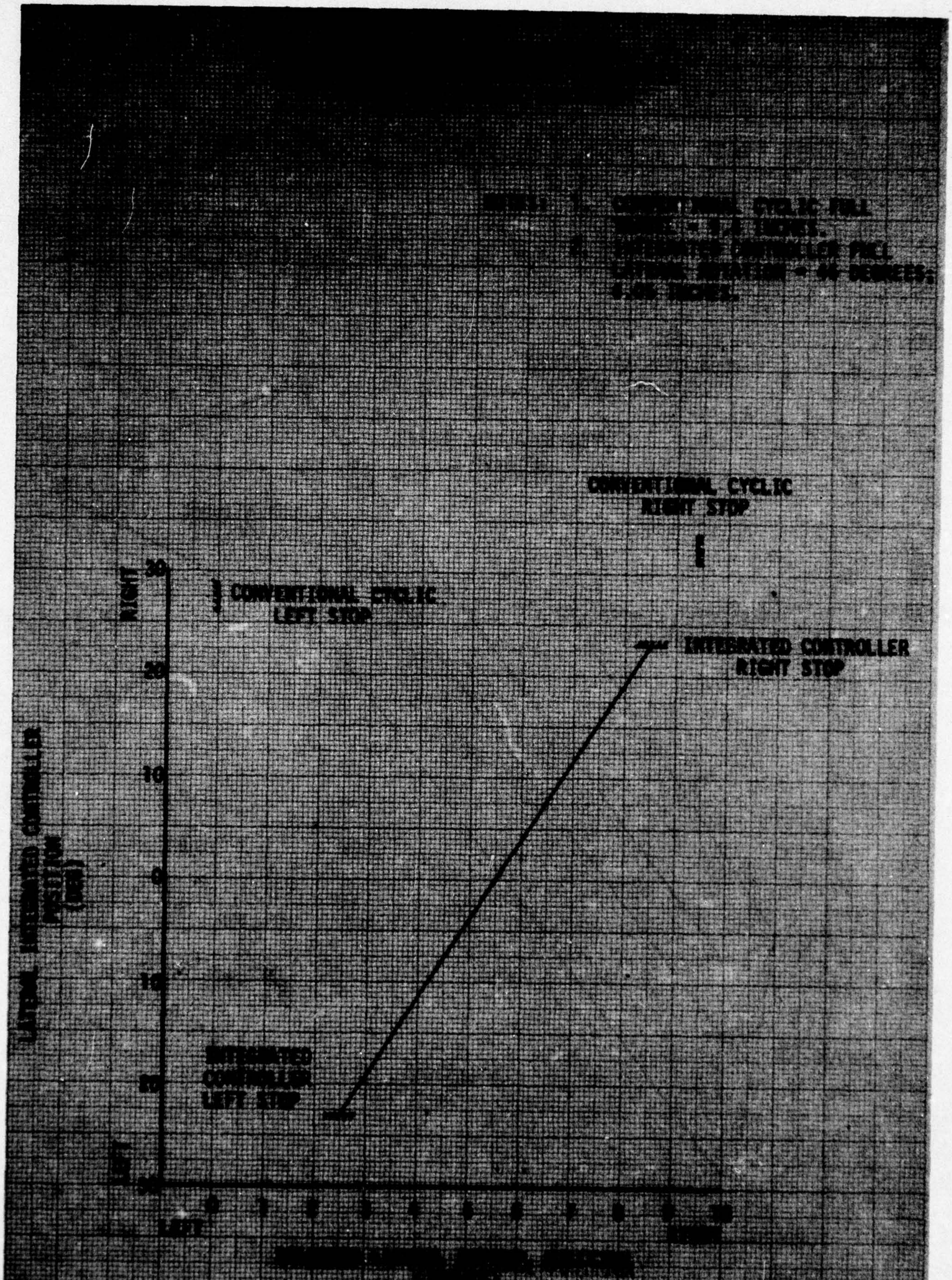
Maneuvering Stability	11 and 12
Controllability	13 through 17
Workload Study	18

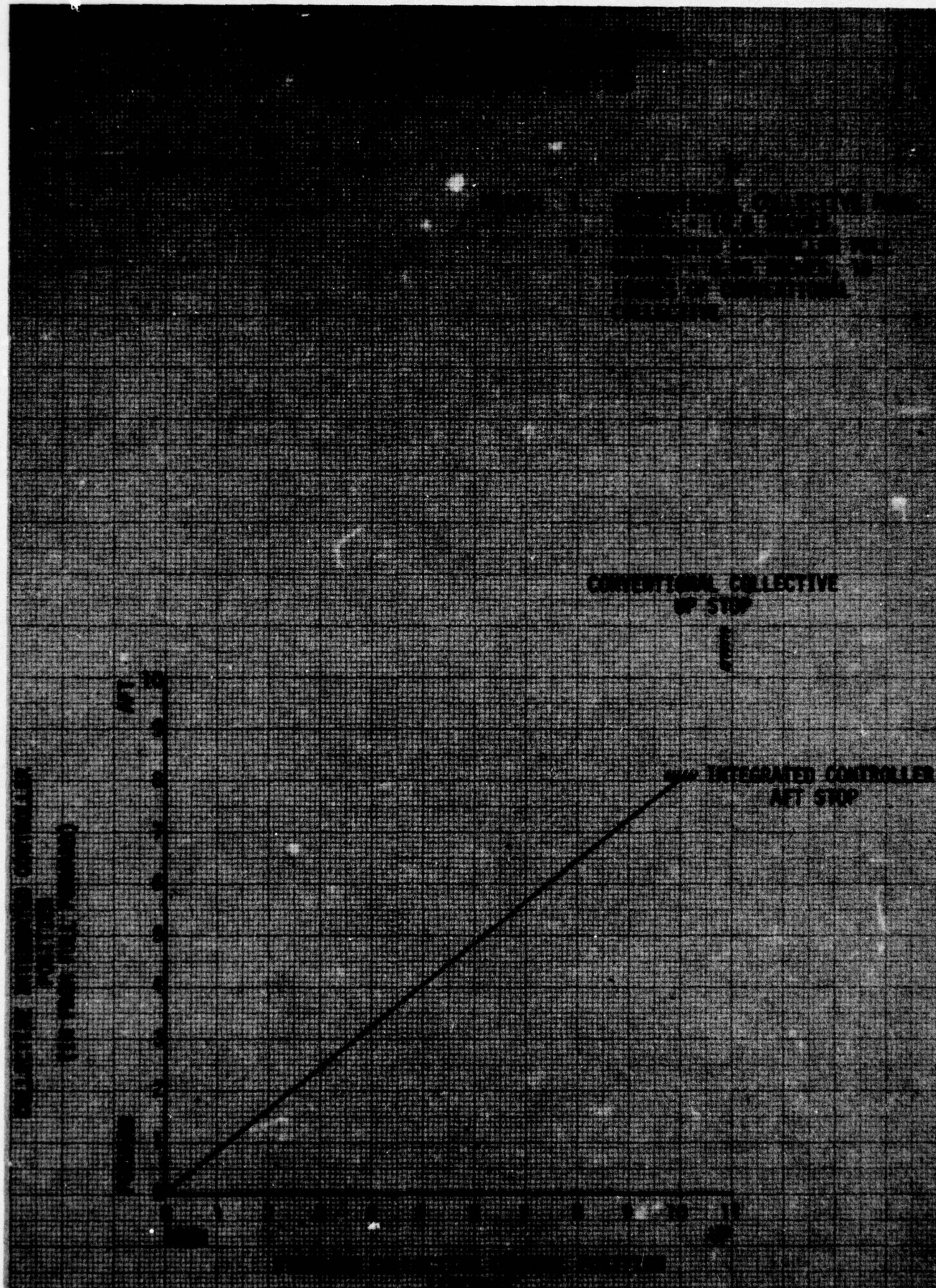
FIGURE 1

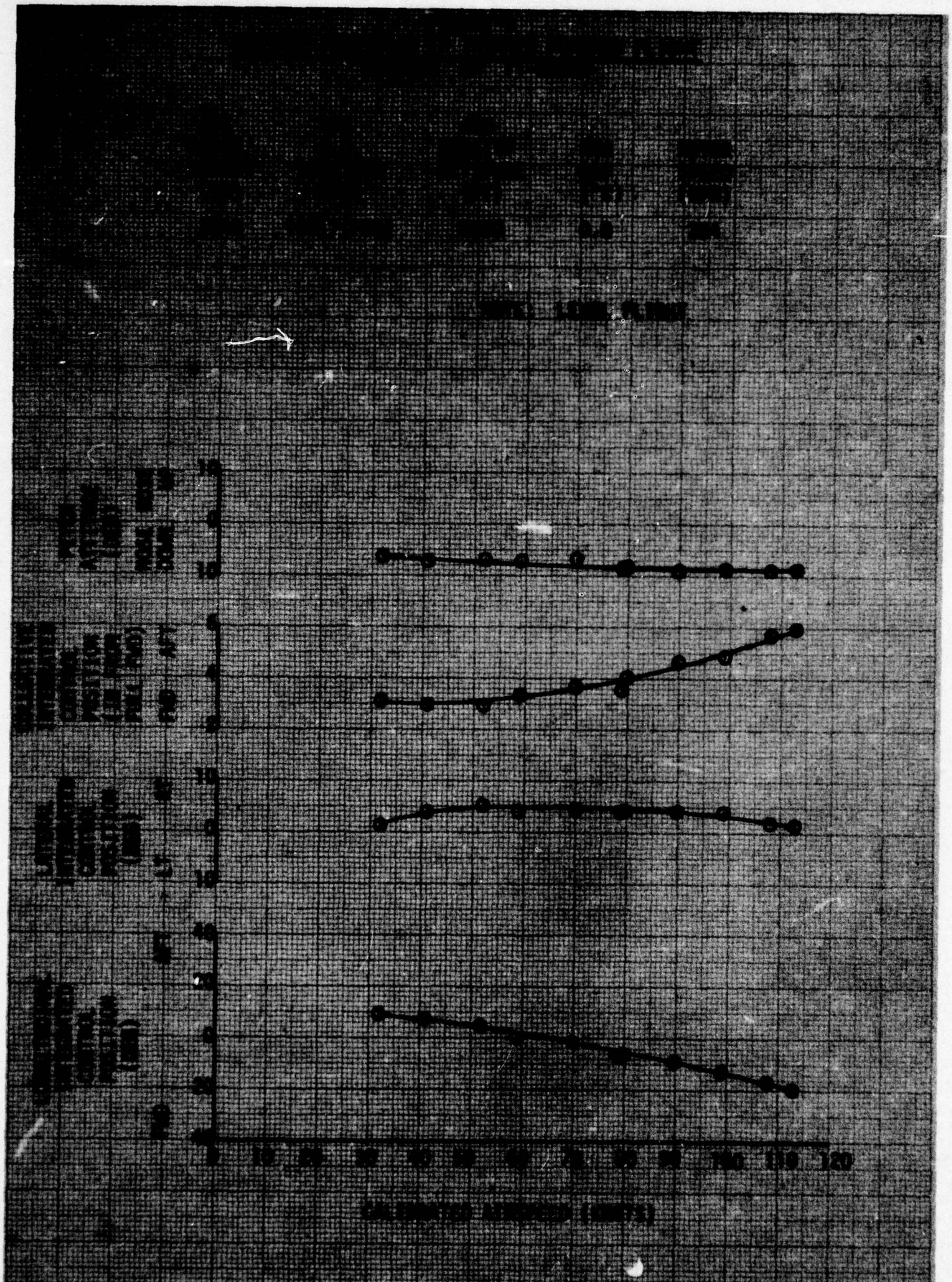
RELATIONSHIP OF CONVENTIONAL LONGITUDINAL CONTROL POSITION TO INTEGRATED CONTROLLER LONGITUDINAL POSITION

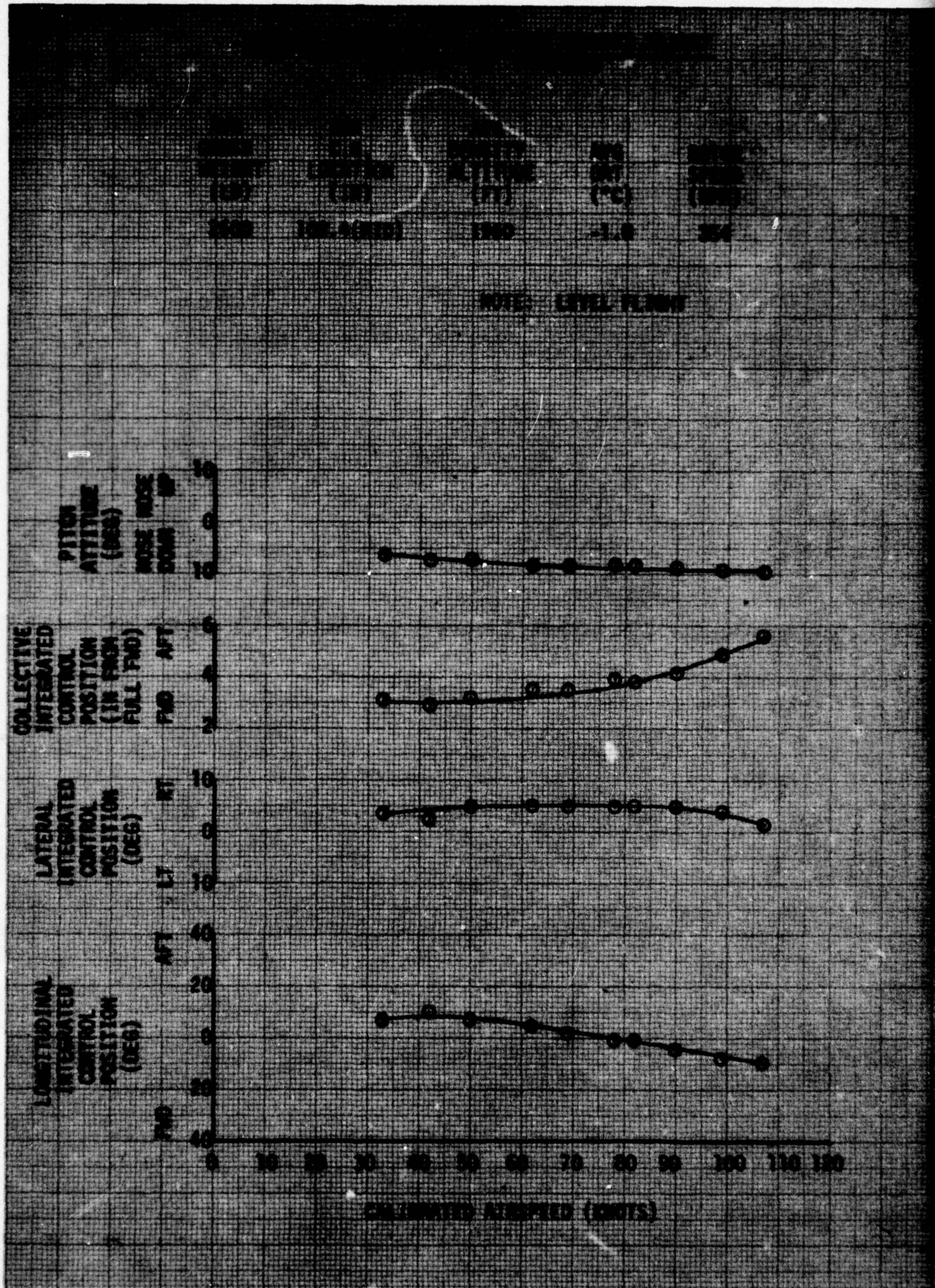
NOTES:
1. CONVENTIONAL CYCLIC FULL TRAVEL = 12.27 INCHES.
2. INTEGRATED CONTROLLER FULL LONGITUDINAL ROTATION = 55.32 DEGREES; 8.34 INCHES.
3. CONVENTIONAL COLLECTIVE FULL TRAVEL = 10.8 INCHES.

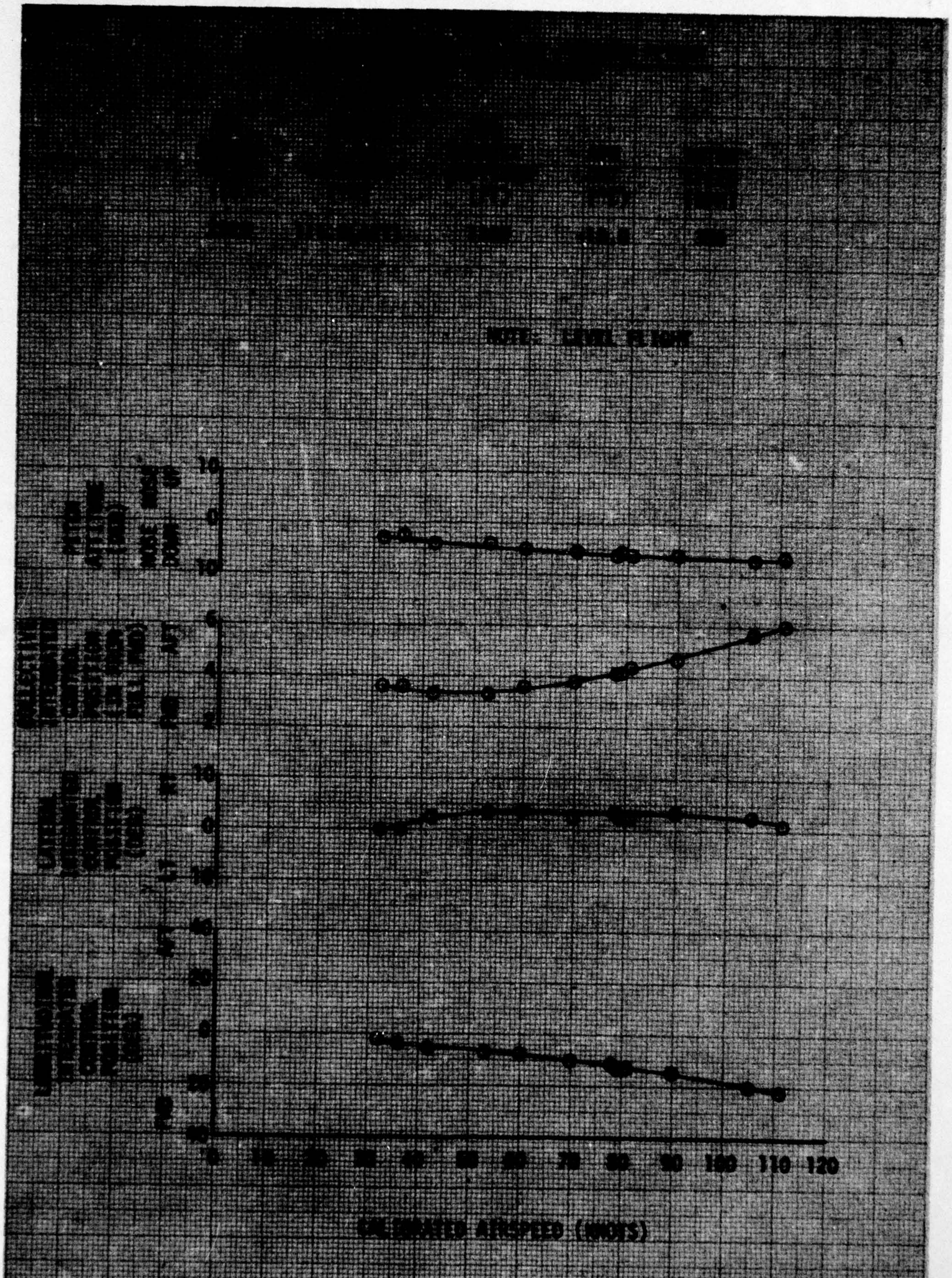


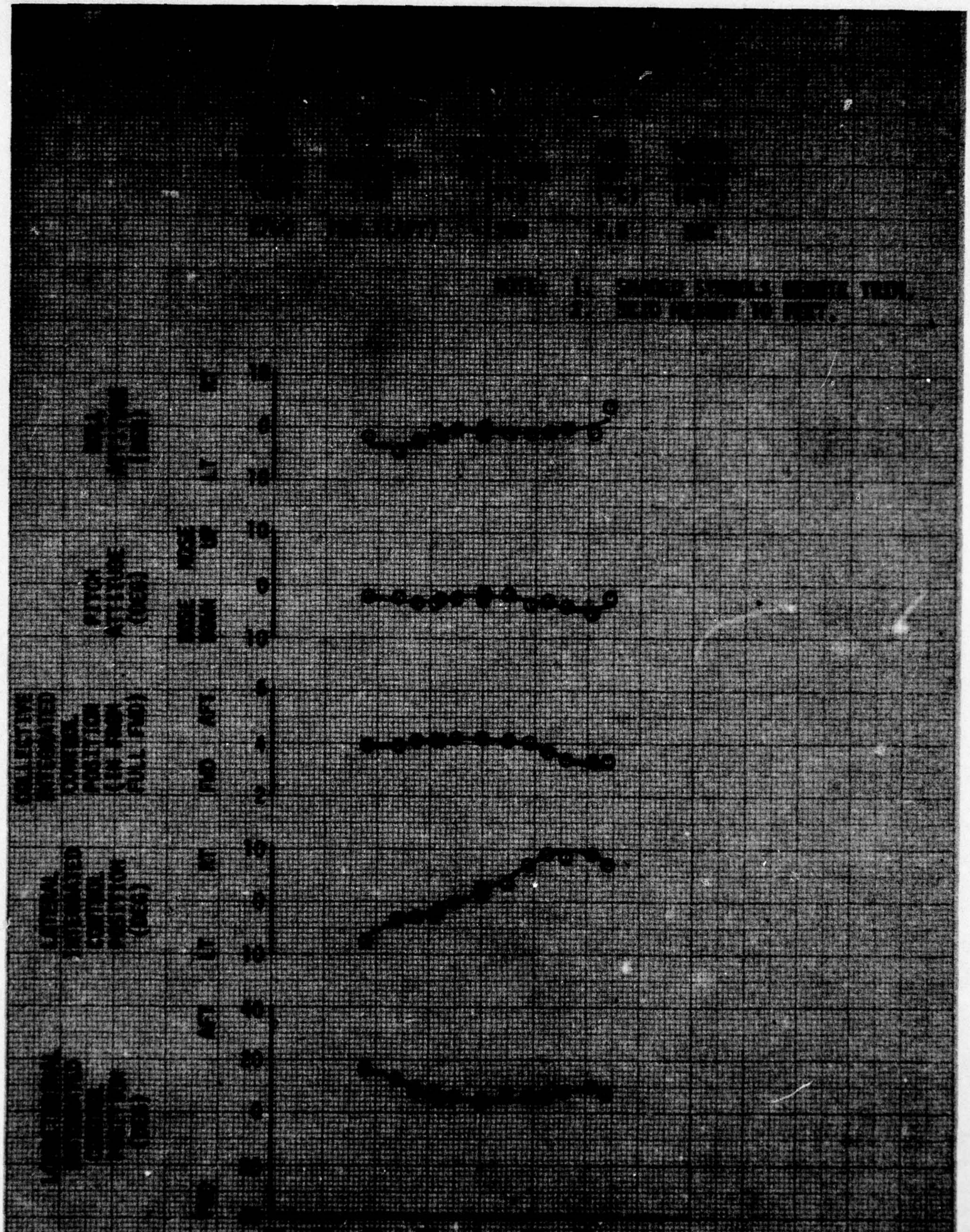

CONVENTIONAL CYCLIC
RIGHT STOP
CONVENTIONAL CYCLIC
LEFT STOP
INTEGRATED CONTROLLER
RIGHT STOP
INTEGRATED
CONTROLLER
LEFT STOP
RIGHT
LEFT
30
20
10
0
10
20
30
LATERAL INTEGRATED CONTROLLER
POSITION
LEFT
RIGHT

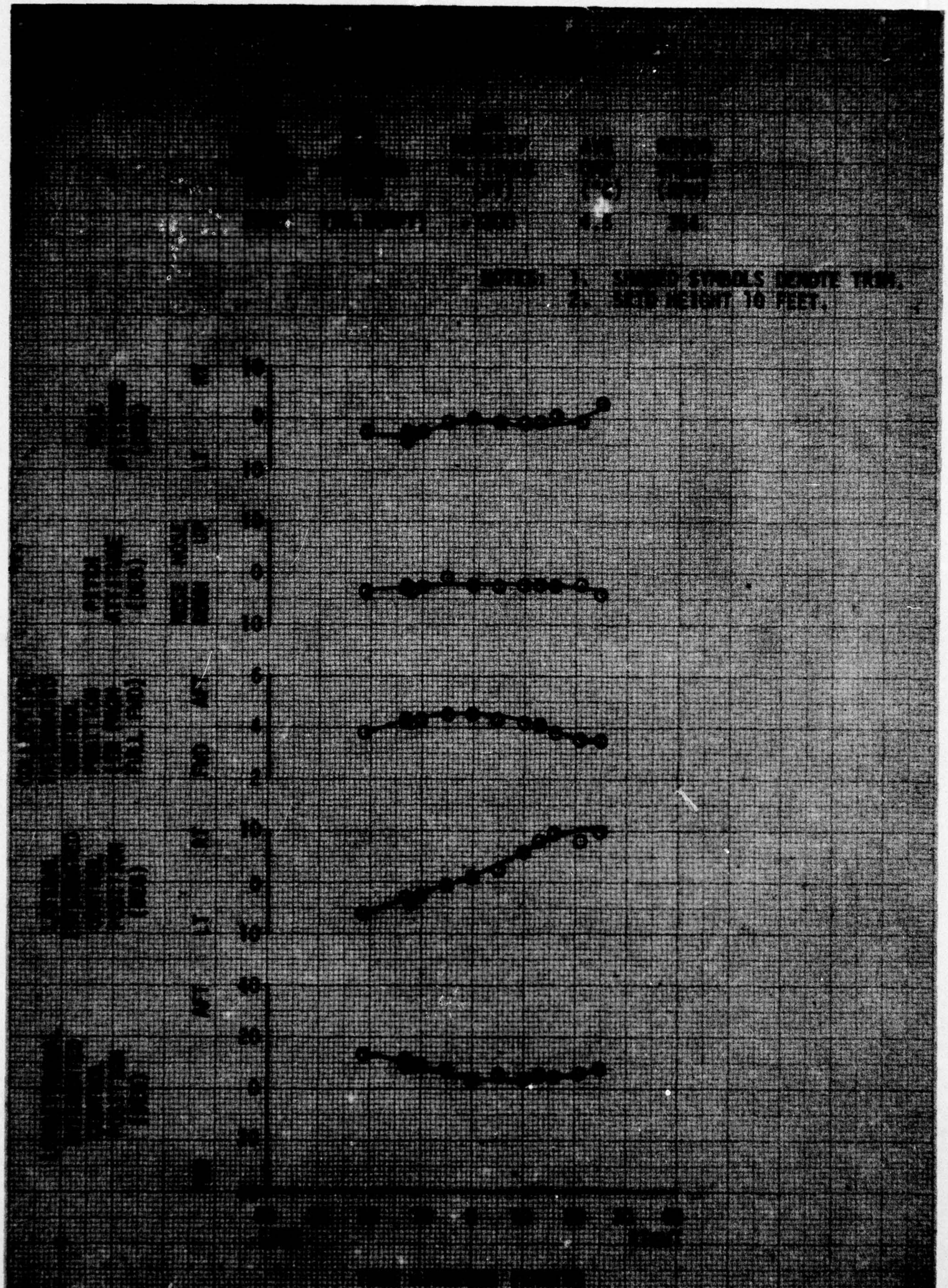

CONVENTIONAL COLLECTIVE
UP STOP
INTEGRATED CONTROLLER
AFT STOP
AFT

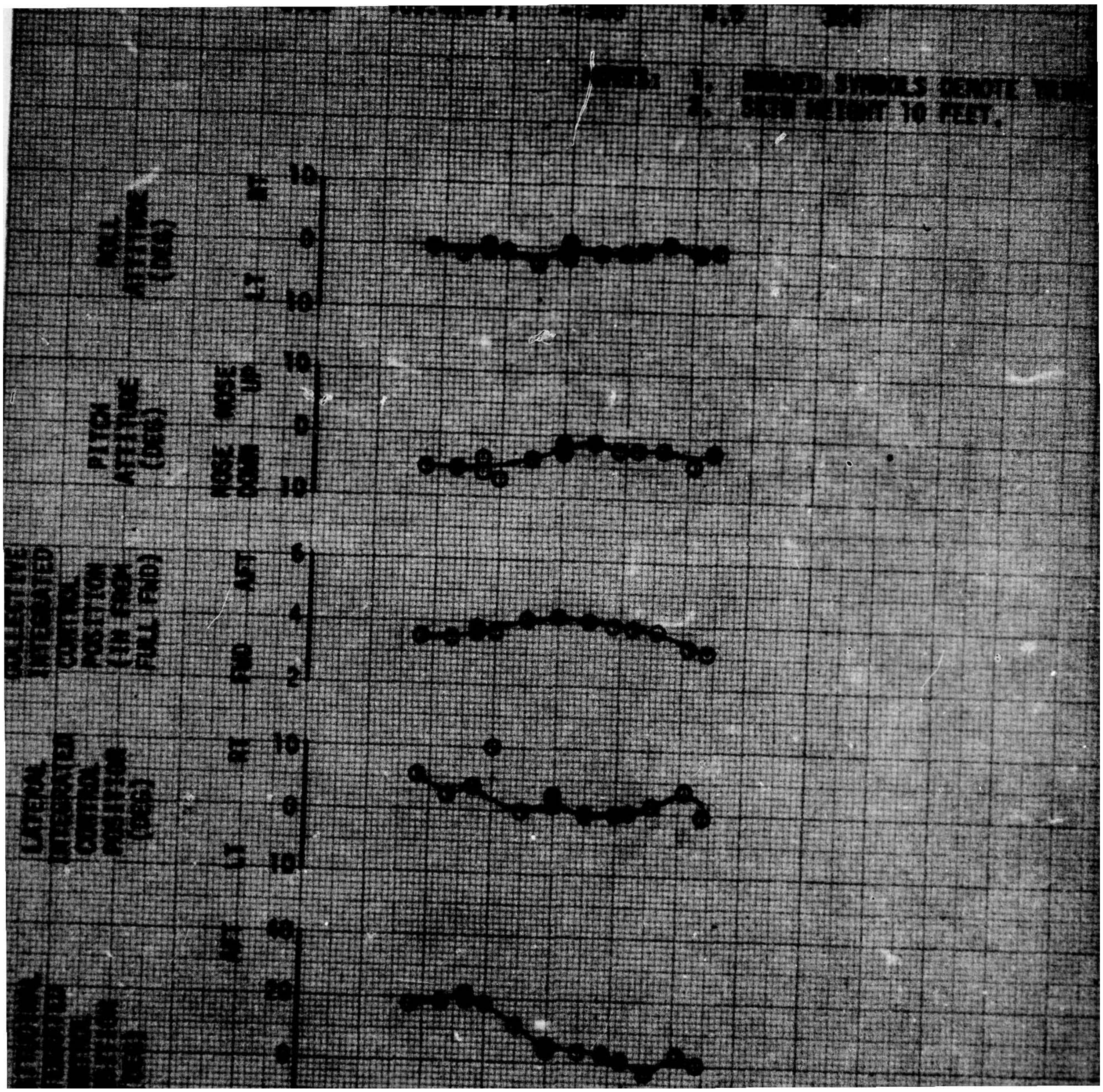

CALIBRATED AIRSPEED (KNOTS)


LONGITUDINAL INTEGRATED CONTROL POSITION (DEG)
FWD
AFT
40
20
0
20
40
LATERAL INTEGRATED CONTROL POSITION (DEG)
LT
RT
10
0
10
COLLECTIVE INTEGRATED CONTROL POSITION (IN FROM FULL FWD)
FWD
AFT
2
4
6
PITCH ATTITUDE (DEG)
NOSE DOWN
NOSE UP
10
0
10
0
10
20
30
40
50
60
70
80
90
100
110
120
CALIBRATED AIRSPEED (KNOTS)
NOTES: LEVEL FLIGHT

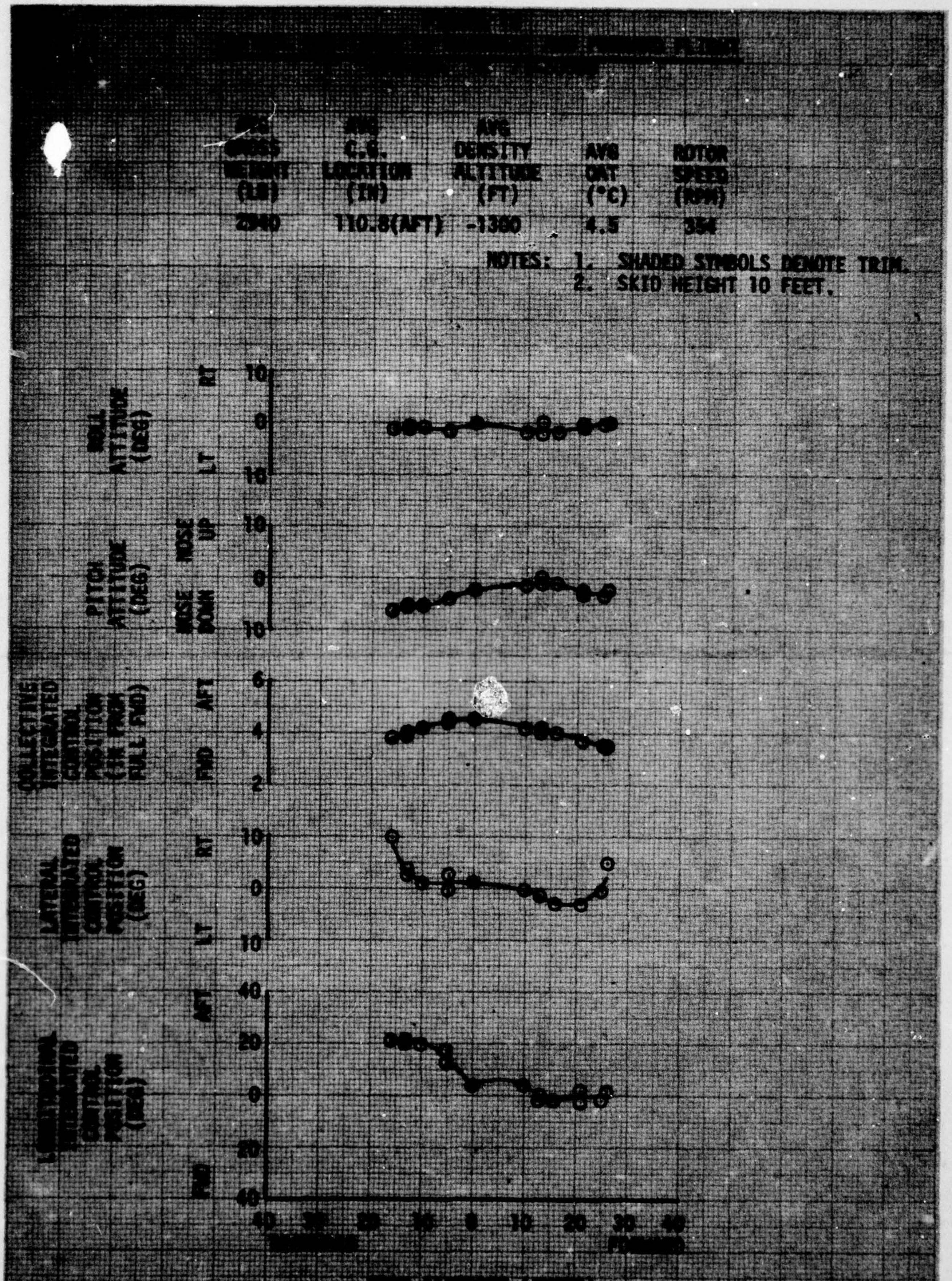

NOTE: LEVEL FLIGHT
110
120

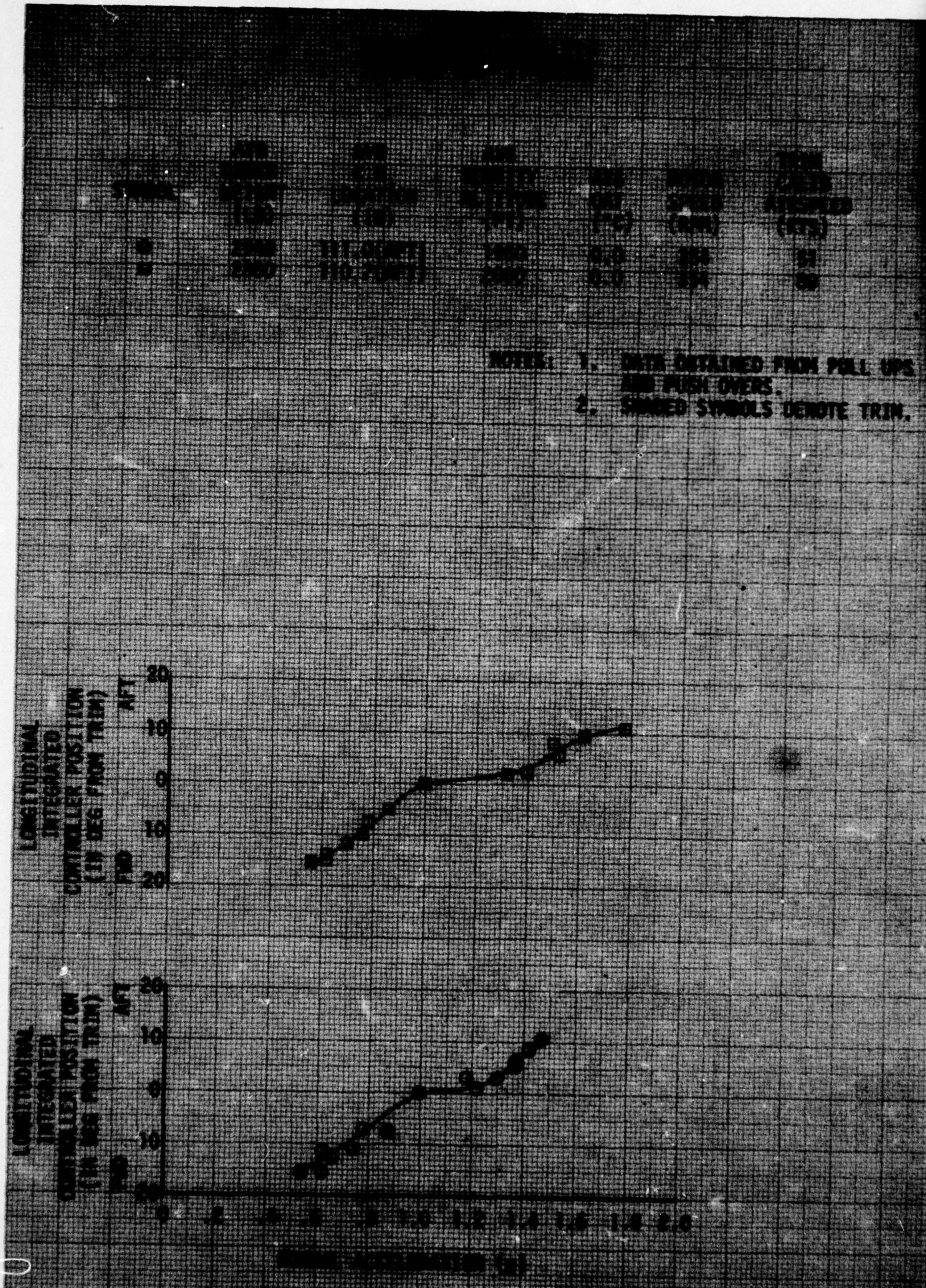



NOTES: 1. SHADED SYMBOLS DENOTE TRIM.
2. SKID HEIGHT 10 FEET.



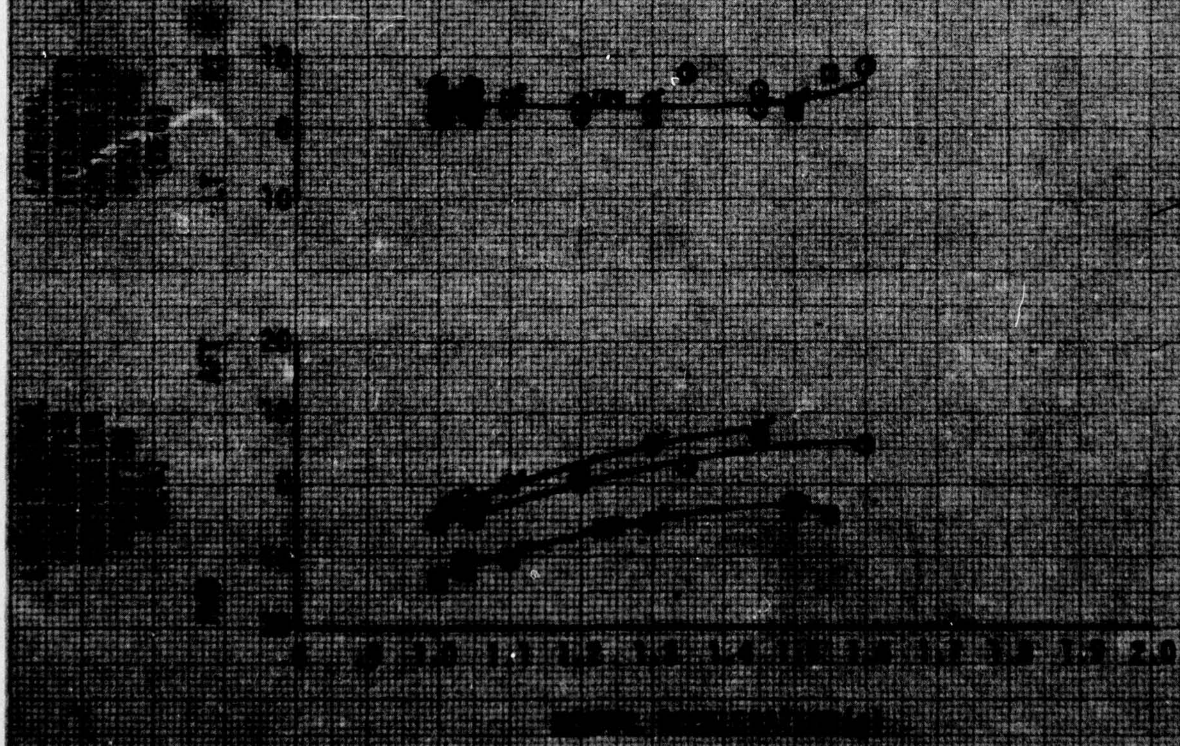
2. SKID HEIGHT 10 FEET.
ROLL ATTITUDE (DEG)
LT
RT
PITCH ATTITUDE (DEG)
NOSE DOWN
NOSE UP
COLLECTIVE INTEGRATED CONTROL POSITION (IN FROM FULL FWD)
FWD
AFT
LATERAL INTEGRATED CONTROL POSITION (DEG)
LT
RT
AFT

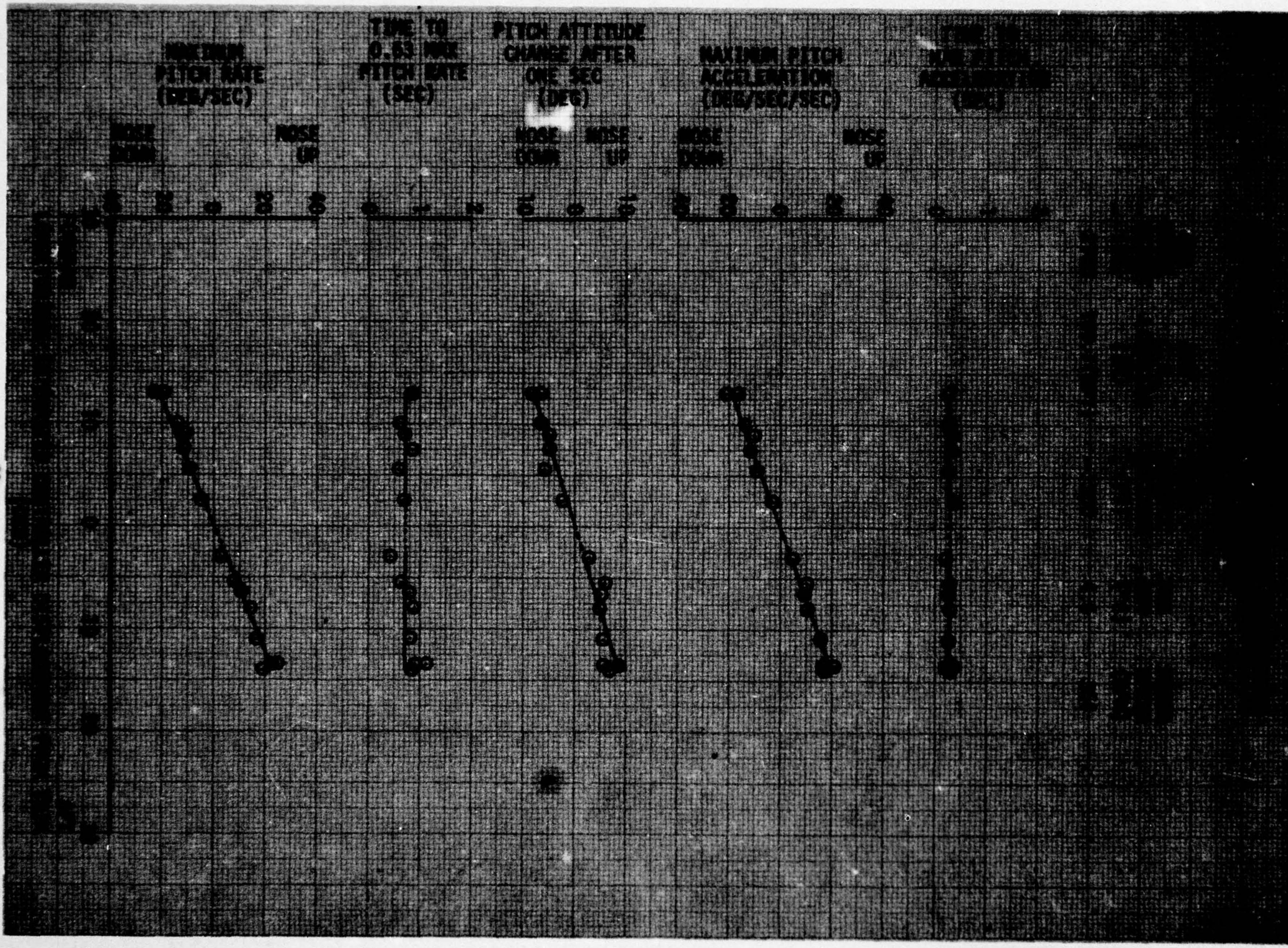

AVG GROSS WEIGHT (LB)
2940
AVG C.G. LOCATION (IN)
110.8(AFT)
AVG DENSITY ALTITUDE (FT)
-1380
AVG OAT (°C)
4.5
ROTOR SPEED (RPM)
354
NOTES: 1. SHADED SYMBOLS DENOTE TRIM.
2. SKID HEIGHT 10 FEET.
ROLL ATTITUDE (DEG)
LT RT
PITCH ATTITUDE (DEG)
NOSE DOWN NOSE UP
COLLECTIVE INTEGRATED CONTROL POSITION (IN FROM FULL FWD)
FWD AFT
LATERAL INTEGRATED CONTROL POSITION (DEG)
LT RT
CONTROL POSITION (DEG)
FWD AFT
FORWARD

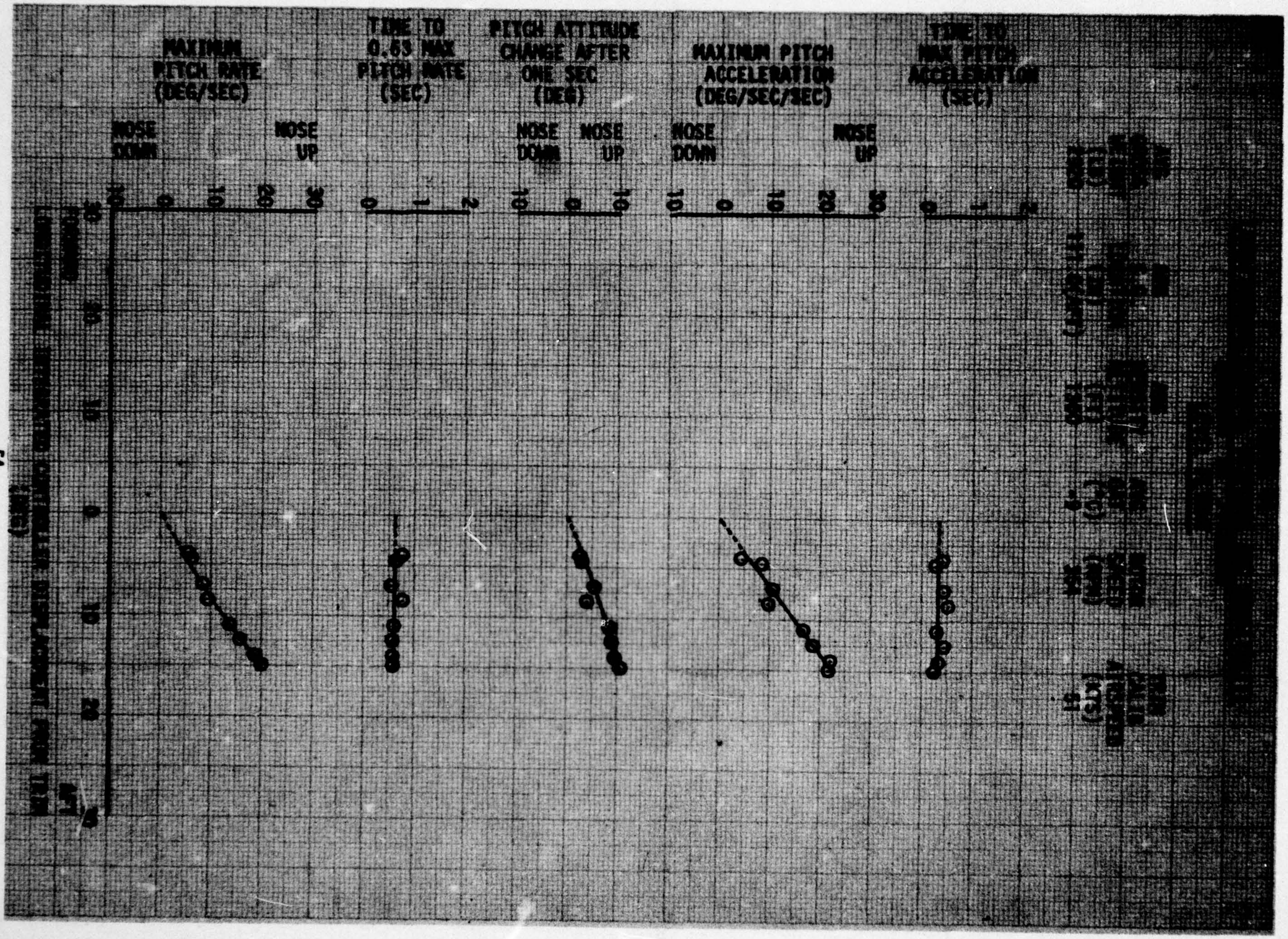

NOTES: 1. DATA OBTAINED FROM PULL UPS AND PUSH OVERS.
2. SHADED SYMBOLS DENOTE TRIM.
LONGITUDINAL INTEGRATED CONTROLLER POSITION (IN DEG FROM TRIM)
FWD
AFT
20
10
0
10
20
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0

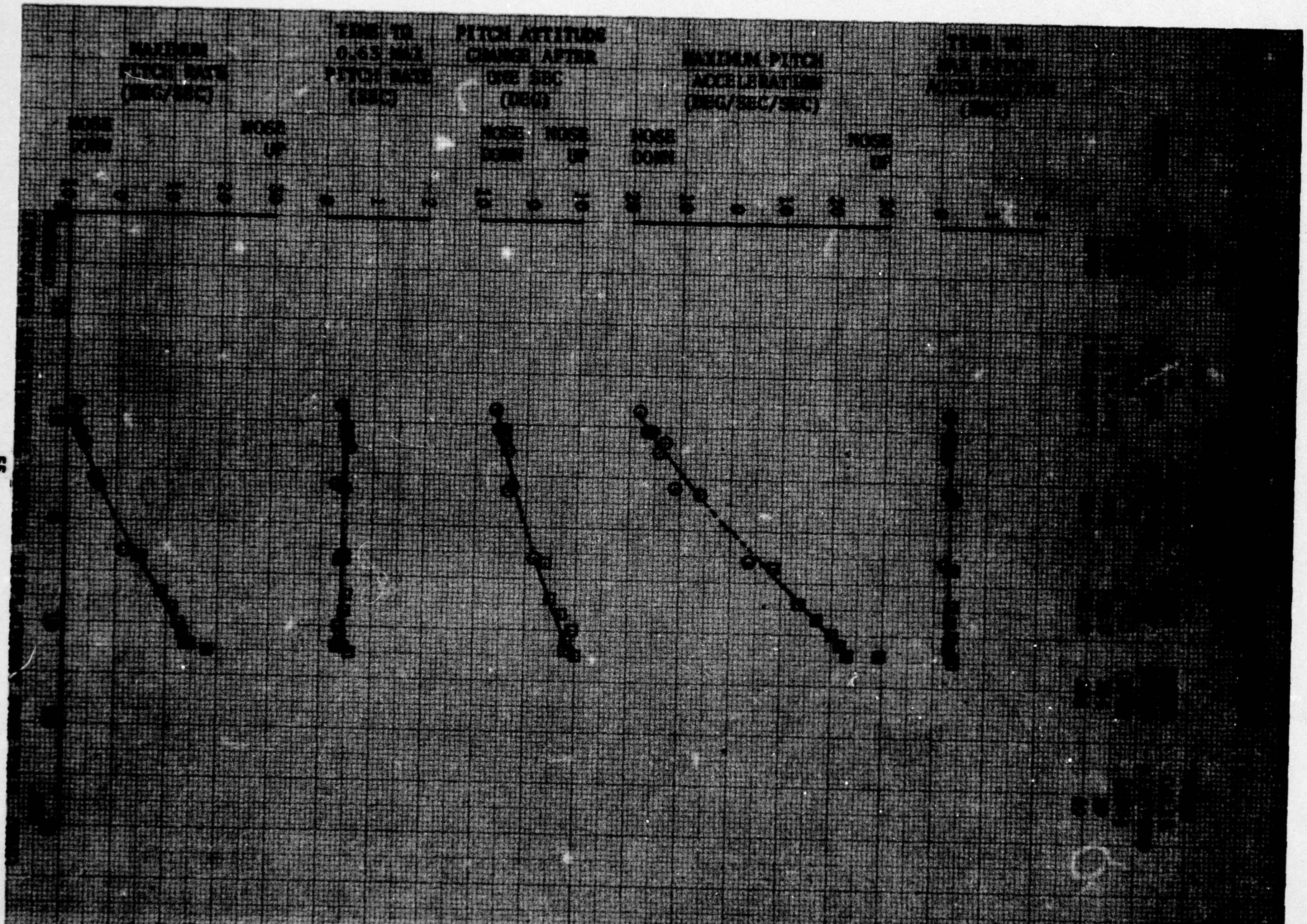
[illegible]	[illegible]	[illegible] LOCATION ([illegible])	[illegible] DENSITY ALTITUDE (FT)	[illegible] OAT (°C)	[illegible]	[illegible]
○	[illegible]	111.8(AFT)	700	-8.5	354	81
□	[illegible]	110.7(AFT)	900	-7.5	354	[illegible]

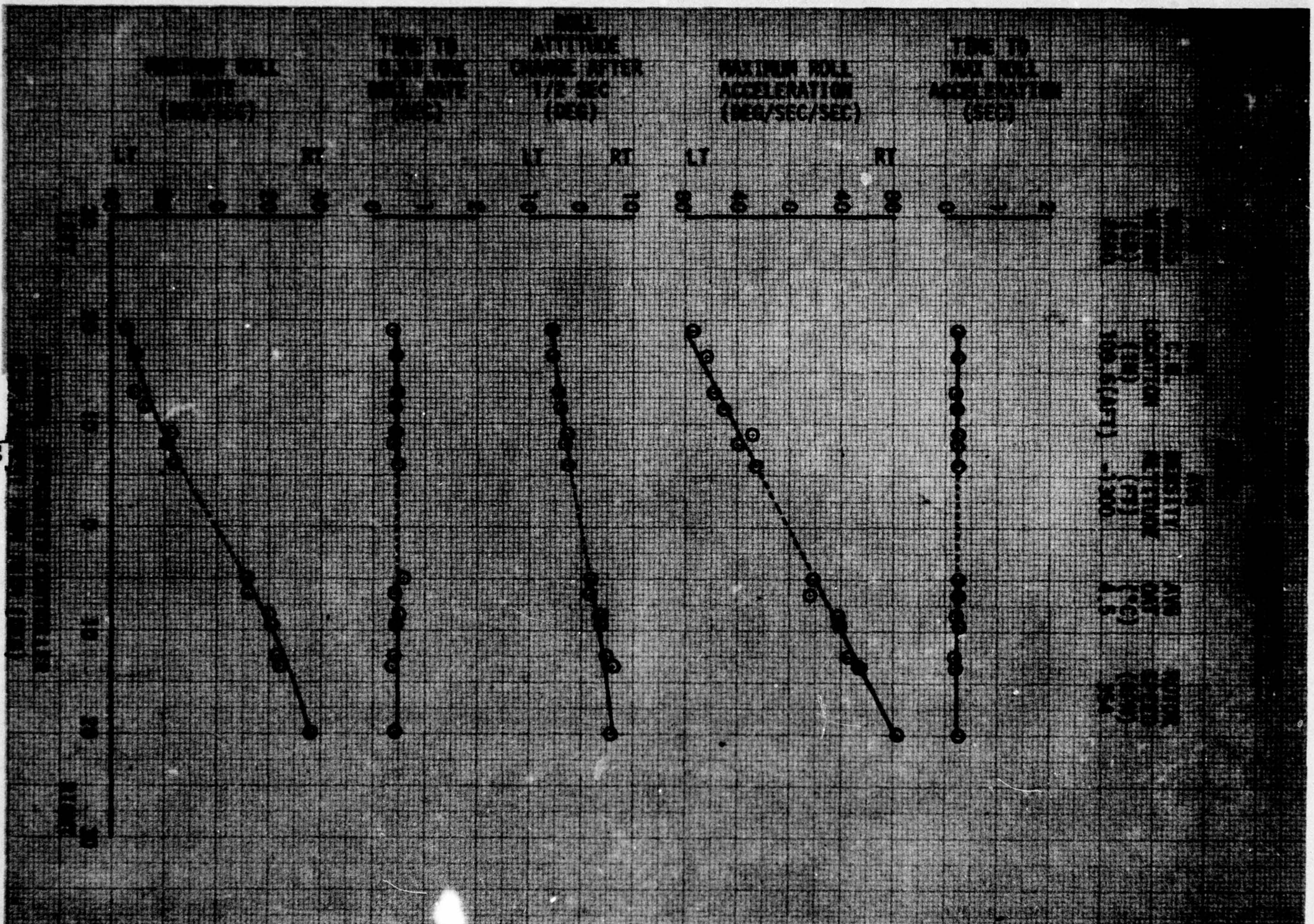
NOTES:
1. DATA OBTAINED FROM WINDUP TURNS.
2. FLAGS DENOTE LEFT BANK.
3. SHADED SYMBOLS DENOTE TRIM IN LEVEL FLIGHT.




MAXIMUM PITCH RATE (DEG/SEC)
NOSE DOWN
NOSE UP
TIME TO 0.63 MAX PITCH RATE (SEC)
PITCH ATTITUDE CHANGE AFTER ONE SEC (DEG)
NOSE DOWN
NOSE UP
MAXIMUM PITCH ACCELERATION (DEG/SEC/SEC)
NOSE DOWN
NOSE UP


MAXIMUM PITCH RATE (DEG/SEC)
NOSE DOWN
NOSE UP
TIME TO 0.63 MAX PITCH RATE (SEC)
PITCH ATTITUDE CHANGE AFTER ONE SEC (DEG)
MAXIMUM PITCH ACCELERATION (DEG/SEC/SEC)
TIME TO MAX PITCH ACCELERATION (SEC)
(KTS)
51
FORWARD
AFT


MAXIMUM PITCH RATE (DEG/SEC)
NOSE DOWN
NOSE UP
TIME TO 0.63 MAX PITCH RATE (SEC)
PITCH ATTITUDE CHANGE AFTER ONE SEC (DEG)
NOSE DOWN
NOSE UP
MAXIMUM PITCH ACCELERATION (DEG/SEC/SEC)
NOSE DOWN
NOSE UP
TIME TO MAX PITCH ACCELERATION (SEC)


AVG
C.G.
LOCATION
(IN)
109.5(AFT)
AVG
DENSITY
ALTITUDE
(FT)
-1300
AVG
OAT
(°C)
4.5
ROTOR
SPEED
(RPM)
354
ROLL
ATTITUDE
CHANGE AFTER
1/2 SEC
(DEG)
MAXIMUM ROLL
ACCELERATION
(DEG/SEC/SEC)
TIME TO
MAX ROLL
ACCELERATION
(SEC)
LT
RT

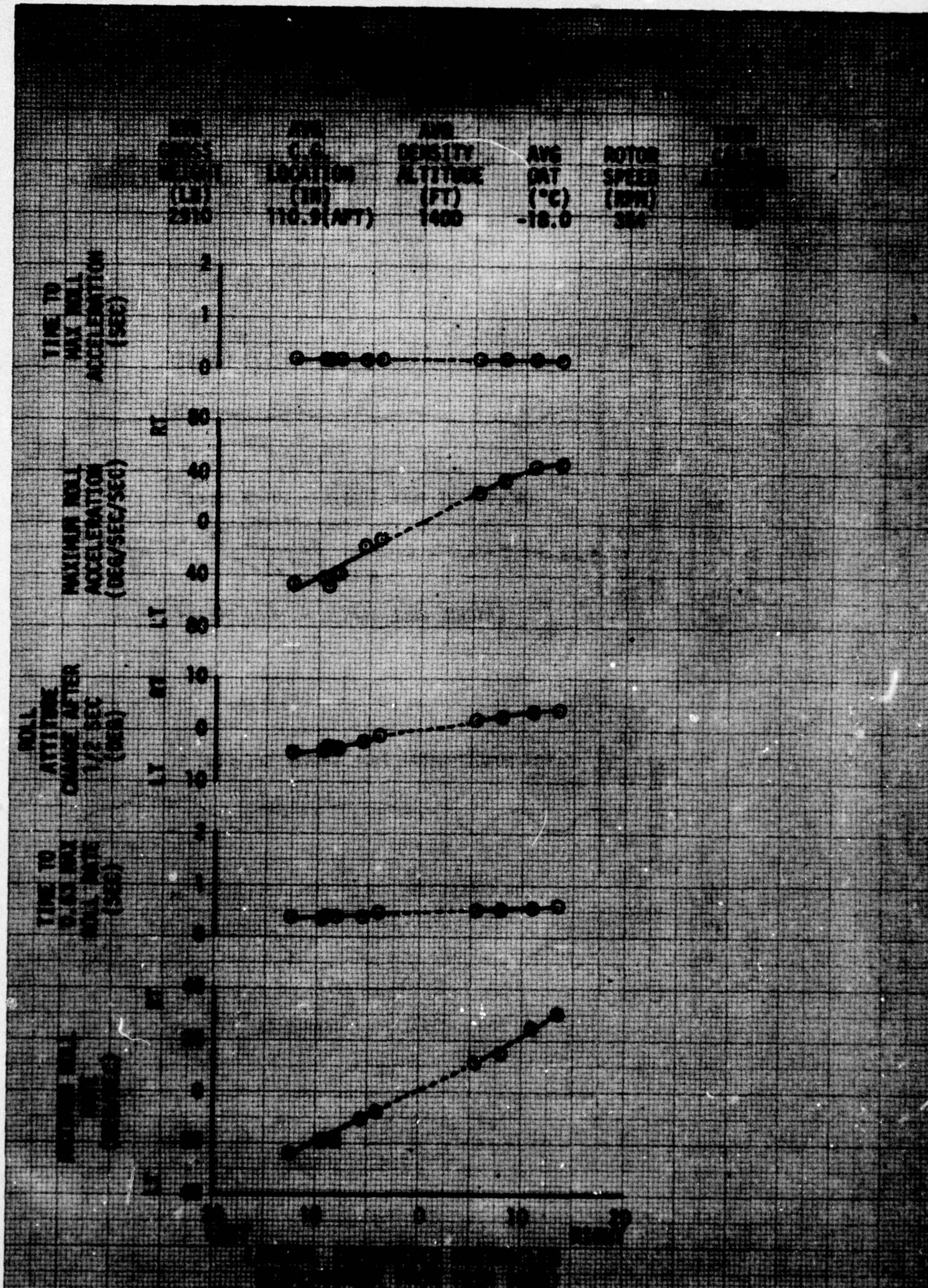
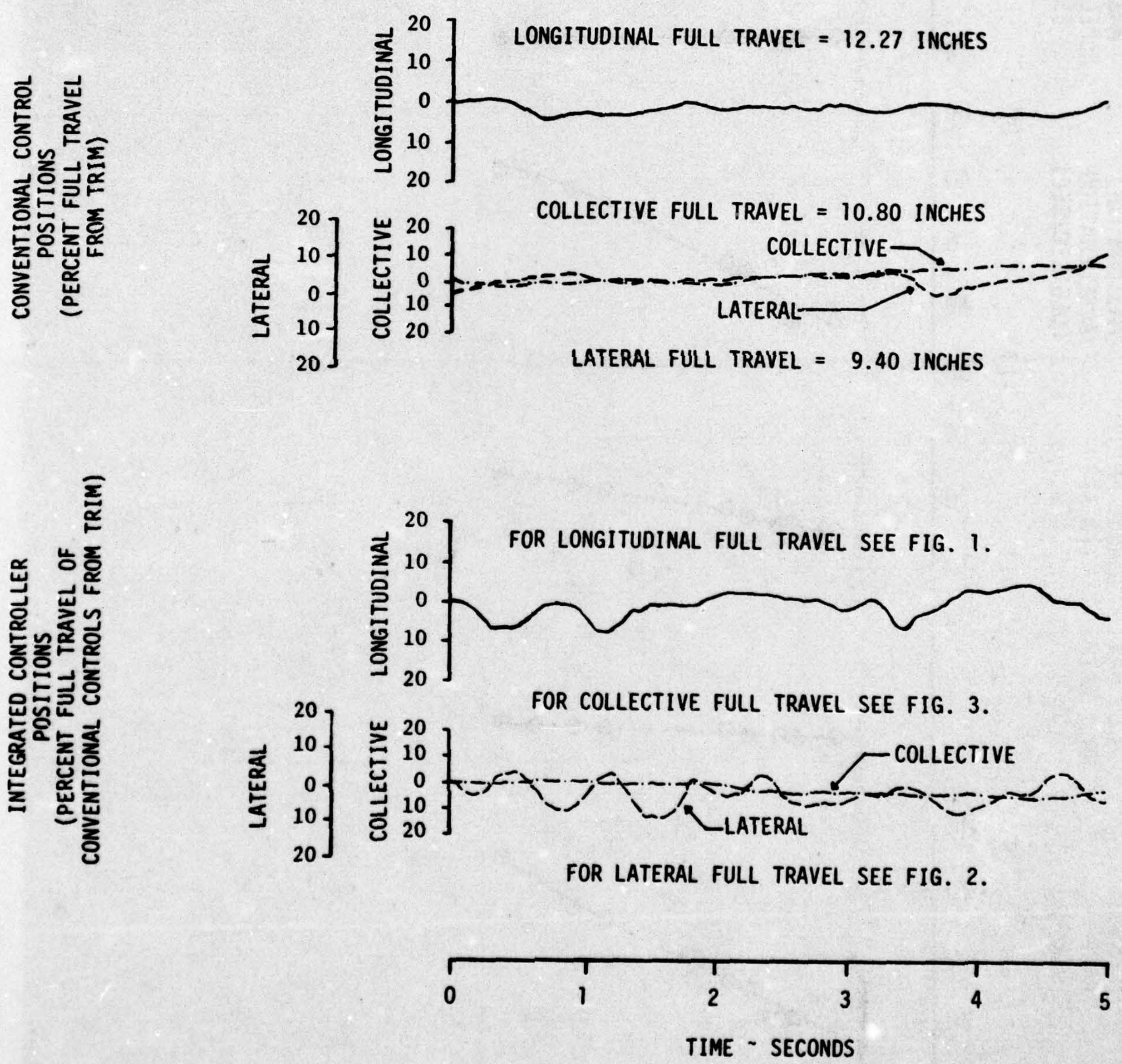

AVG C.G. LOCATION (IN) 110.9(AFT)
AVG DENSITY ALTITUDE (FT) 1400
AVG OAT (°C) -18.0
ROTOR SPEED (RPM)
TIME TO MAX ROLL ACCELERATION (SEC)
MAXIMUM ROLL ACCELERATION (DEG/SEC/SEC)
ROLL ATTITUDE CHANGE AFTER 1/2 SEC (DEG)
LT
RT

FIGURE 18
PILOT WORKLOAD AT STABILIZED 3 FOOT HOVER
JOH-58A S/N 71-20380

NOTES: 1. AVG GROSS WEIGHT = 2850 LBS.
2. AVG CENTER OF GRAVITY LOCATION = 110.7 INCHES AFT.



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Ames Directorate, US Army Air Mobility R&D Laboratory (SAVDL-AM)	2
Eustis Directorate, US Army Air Mobility R&D Laboratory (SAVDL-EU-SY)	2
Langley Directorate, US Army Air Mobility R&D Laboratory (SAVDL-LA)	2
Lewis Directorate, US Army Air Mobility R&D Laboratory (SAVDL-LE-DD)	1
US Army Aeromedical Research Laboratory	1
US Army Aviation Center (ATZQ-D-MT)	3
US Army Aviation School (ATZQ-AS, ATST-CTD-DPS)	3
US Army Aircraft Development Test Activity (PROV) (STEBG-CO-T, STEBG-PO, STEBG-MT)	5
US Army Agency for Aviation Safety (IGAR-TA, IGAR-Library)	2
US Army Maintenance Management Center (DRXMD-EA)	1
US Army Transportation School (ATSP-CD-MS)	1

US Army Logistics Management Center	1
US Army Foreign Science and Technology Center (AMXST-WS4)	1
US Military Academy	3
US Marine Corps Development and Education Command	2
US Naval Air Test Center	1
US Air Force Aeronautical Division (ASD-ENFTA)	1
US Air Force Flight Dynamics Laboratory (TST/Library)	1
US Air Force Flight Test Center (SSD/Technical Library, DOEE)	3
US Air Force Electronic Warfare Center (SURP)	1
Department of Transportation Library	1
US Army Bell Plant Activity (SAVBE-ES)	5
Detroit Diesel Allison Division of General Motors Corporation	1
Defense Documentation Center	12